ASSESSMENT OF POTENTIAL GROUND-WATER QUALITY IMPACTS OF MINING AND WASTE DISPOSAL AT THE SAN JUAN MINE, NEW MEXICO

A Draft Report to be incorporated into the
San Juan Mine Permit Application

Submitted to:

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NOTICE

Radian Corporation, acting as a consultant to the San Juan Coal Company (SJCC) developed the report entitled "Assessment of Potential Ground-Water Quality Impacts of Mining and Waste Disposal Operations at the San Juan Mine, New Mexico." In the interest of conserving the efforts of SJCC staff, the report was written in a manner such that it could be easily incorporated into the San Juan Mine Permit Application. This entailed the removal of certain references differentiating between data and interpretations developed by SJCC and/or Radian Corporation.

BACKGROUND

The San Juan Coal Company (SJCC), an operating company of Utah International, Inc. operates the San Juan Coal Mine near Farmington, New Mexico. Wastes from the adjacent San Juan Power Plant (operated by the Public Service Company of New Mexico) are proposed to be deposited in the mine areas as they are backfilled and reclaimed. The purpose of this study was to evaluate potential impacts on ground-water quality and ground-water receptors by mining and waste disposal operations.

On 26 July 1983 Radian Corporation submitted a preliminary proposal for the assessment of potential impacts to ground-water quality and ground-water receptors. The proposal and follow-up work plan detailed the methods by which Radian would assist SJCC staff in the evaluation of potential ground-water quality impacts by conducting spoil/waste analysis and leaching and equilibration laboratory studies. These laboratory studies were to provide a knowledge of the chemical and physical characteristics of the spoil/waste materials and the chemical interaction of the leachate with affected ground water and geologic media. In addition, the proposal described the methods by which Radian would assist SJCC staff in the acqusition and implementation of a widely accepted, numerical ground-water mass transport model for the evaluation of potential contaminant transport in affected water bearing units.

After several visits to the San Juan Mine by Radian staff and subsequent analysis of available data, Radian determined that the use of a numerical ground-water model was not required for the evaluation of potential ground-water quality impacts. This judgement was based on the lack of pre-mining or background data needed to facilitate model calibration and the appropriate use of such a model. In light of the apparent inappropriateness of applying this type of model for the assessment of potential impacts, an alternate course of study was recommended by Radian.

A revised scope of work for the assessment of potential impacts to ground-water quality was submitted to SJCC on 26 September. The revised scope of work included the laboratory studies described in the previous scope of work and presented alternate methodologies by which potential contaminant transport would be evaluated. These alternate methodologies included a detailed hydrogeological evaluation of the stratigraphic units potentially affected by mining operations and the development of a conceptual model for leachate transport in this system. Analytical and simplified numerical techniques for estimating the spatial and temporal distribution of potential ground-water contaminants were discussed as an uncosted option, should they be required. The revised scope of work was presented to the personnel of the New Mexico Mining and Minerals Division, New Mexico Environmental Improvement Division, the Bureau of Land Management, and the Office of Surface Mining on 29 August. Written approval for the revised scope of work was received by SJCC from the Office of Surface Mining in early October.

27.2.1 Assessment of Potential Ground-Water Quality Impacts

27.2.1.1 Introduction

The assessment of potential impacts to ground-water quality and potential receptors from mining and waste disposal operations at the San Juan Mine was conducted in two distinct, yet interdependent efforts. These two efforts are referred to as the laboratory and the ground-water leachate transport studies. Laboratory studies were conducted to evaluate the potential point-of-contact chemical impact of spoil/waste materials on ground-water quality in Coal Seam No. 8 of the Fruitland Formation. This coal seam was selected as the stratum of principal study because it is the principal water bearing unit of concern with respect to water quality impacts. The rationale for the selection of Coal Seam No. 8 is discussed in 27.2.1.3.

Laboratory studies for the evaluation of point-of-contact chemical impacts on ground-water quality in Coal Seam No. 8 included the sampling and analysis of power plant ash wastes and ground water. Separate leaching studies were performed using composited mine spoil samples and a composite mixture of mine spoil and power plant ash wastes to evaluate the water quality impact on ground water as it flows through the reclaimed mine areas. Leachates derived from the composited leaching tests were exposed to coal samples from Seam No. 8 in batch equilibration tests to determine the potential for attenuation of potential ground-water contaminants by the coal seam. Compaction and permeability tests were performed on the composited spoil and waste materials as a means to assess the post-mining hydraulic properties of the reclaimed mine areas. The methodologies and results of the laboratory studies are presented in Section 27.2.1.2.

Leachate transport studies consisted of the hydrogeologic assessment of geologic formations and related receptor points potentially affected by mining and waste disposal operations. These efforts included the collection and assimilation of hydrogeologic data available in the literature. Once significant pathways (strata) for leachate transport were identified, an analysis of projected travel times and flow volumes in affected units was performed. The results of these analyses were considered with the results and conclusions of the laboratory chemical studies to estimate potential water quality impacts of mining and waste disposal operations. The results and methodologies of the leachate transport evaluations are discussed in Section 27.2.1.3.

27.2.1.2 Laboratory Analysis of Spoil/Waste and Chemical Interactions With Ground Water and Geologic Materials

The purpose of this phase of the water quality impact assessment was to use state-of-the-art laboratory tests to estimate the potential for contaminant migration from the spoil/waste in the mine. This was accomplished by leaching mine spoil samples and spoil-plus-waste samples with ground water from Coal Seam No. 8. The impact of the spoil and waste on the ground-water quality was determined by analyzing the water before and after equilibration with the solids. The analytical parameters measured are those regulated by the New Mexico Water Quality Control Commission (WQCC Sect. 3-103).

After reclamation, ground water moving through the mine area will travel through the abutting coal seam, where chemical contaminants in the water will interact with the coal. This interaction could result in a reduction or attenuation of any contaminants mobilized from the spoil or waste. To assess this attenuation, laboratory leachates generated from the interactions between ground water and spoil or waste were equilibrated with samples of coal from the water-bearing seam (Seam No. 8). The resultant attenuate was again analyzed for the ground-water quality parameters, and the results were compared to the leachate quality data to assess attenuation potential.

In addition to the chemical interaction studies described above, several other laboratory tests were performed in support of the impact assessment. These tests included permeability measurements on the spoil and waste, EPA toxicity tests on the waste, and whole-sample chemical analysis of the waste.

The approach for obtaining media samples and for conducting the laboratory testing is contained in Section 27.2.1.2.1 and 27.2.1.2.2. The results of the laboratory testing and discussion of the results as they pertain to the assessment of ground-water impacts are contained in Section 27.2.1.2.3.

27.2.1.2.1 Media Sampling

The sources of various media samples that were collected for this evaluation are listed on Table 27.2.1-1. The following paragraphs describe the procedures for the collection of each media type.

TABLE 27.2.1-1. SOURCES OF SAMPLES COLLECTED FOR LABORATORY TESTS

Sample	Source
Fruitland Formation Ground-Water	SJCC Well Nos. 2, 3, 8, 9 (completed in Coal Seam No. 8)
Mine Spoil	Composite grab sample from spoil areas across the mine
Precipitator Ash	Coal ash from storage silos, collected during truck loading
Bottom Ash	Ash heap at bottom of boiler
Process Water Treatment Sludge	Dump trucks during loading from chemical plant centrifuges
Coal	Core samples from Coal Seam No. 8 (obtained during the drilling of SJCC Fruitland Wells Nos. 12, 14, 15 and 16)

Fruitland Formation Ground Water

As noted, the water-bearing unit which was identified as being possibly impacted by the mining and waste disposal operations is Coal Seam No. 8. Ground water from this unit was collected on August 14, 1983 from four SJCC wells (well nos. 2, 3, 8, and 9) and composited. The well locations are indicated in Figure 27.2.1-1. (Also shown on the map are the sampling locations for the spoil and coal.) The wells were selected because they are well distributed over the mine area.

The ground water was sampled from four-inch diameter PVC-cased wells using positive air displacement. Four liters were collected* from each well in linear polyethylene containers and immediately placed on ice. These samples were express air freighted to Radian laboratories in Austin, Texas where they were immediately filtered and composited. A fraction of the composite sample was preserved for chemical analysis. Preservervation for analysis was conducted according to the methods listed in Table 27.2.1-2. The remainder of the ground water sample (approximately 12 liters) was stored at 4°C for use in the batch leaching and attenuation tests.

TABLE 27.2.1-2. METHODS OF PRESERVATION OF LIQUID SAMPLES FOR CHEMICAL ANALYSIS

Chemical Parameter	Preservation
Elemental analysis (trace and major species)	pH <2 with HNO_3
Major anions, TDS and pH	Cool 4°C
Phenol	pH <2 with H_2SO_4
Cyanide	pH >12 with NaOH
Radionuclides	pH <2 with HNO_3

* Ground-water sampling was performed by SJCC personnel.

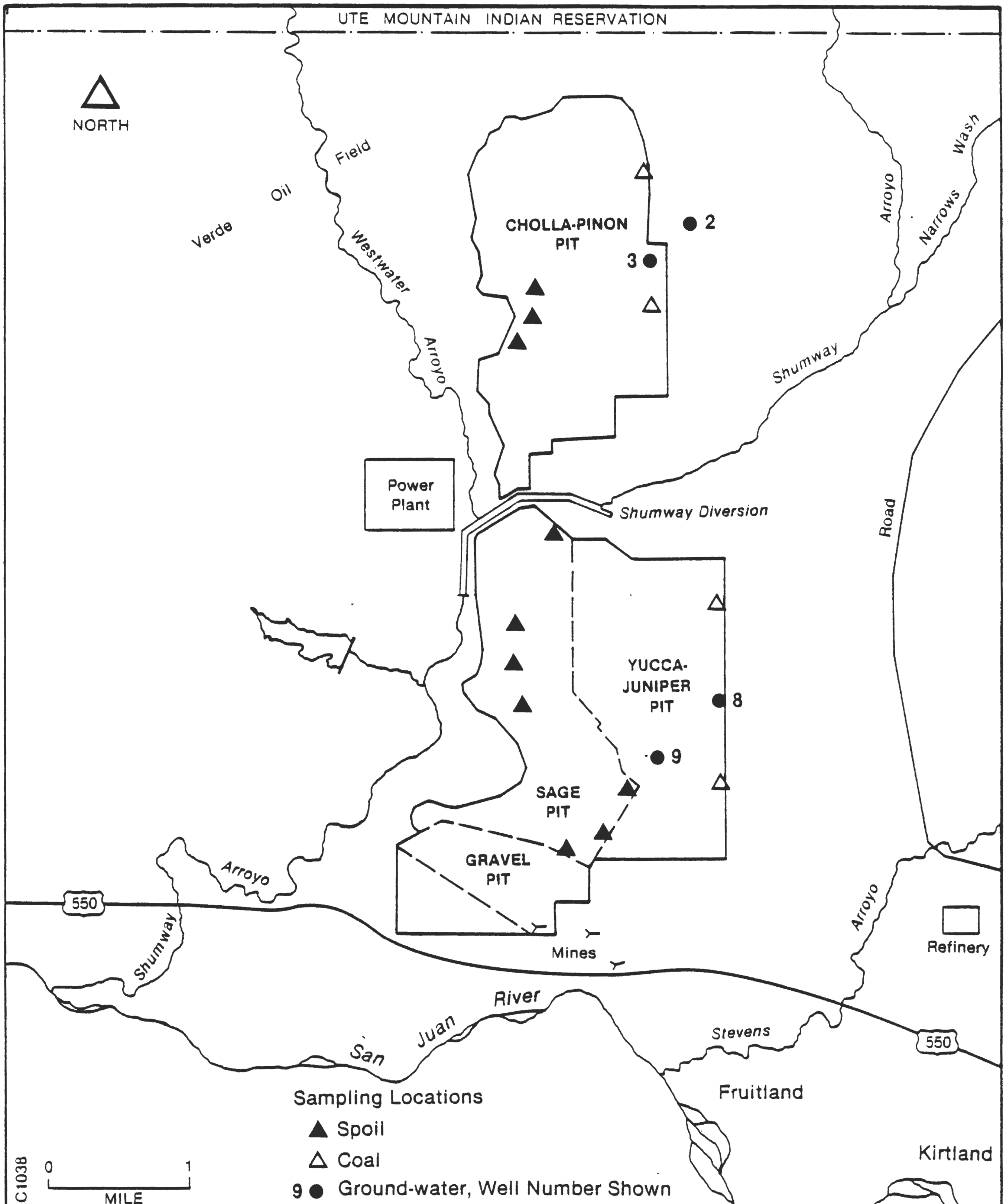


Figure 27.2.1-1. Sampling Locations at the San Juan Coal Mine.

Mine Spoil

A spoil sample representing the average composition of the mine spoil was collected as a composite of 10 grabs by Radian on August 11, 1983. Figure 27.2.1-1 shows the sampling locations of the spoil materials.

As seen in Figure 27.2.1-1, a good areal distribution of spoil material sampling points was used. In addition, care was used to ensure that grab samples were taken from spoils representing various depths of origin in the mine.

The spoil grab samples were well mixed and split down to a workable size (approximately 20 pounds) for shipment to Radian. The samples were then crushed to pass a No. 10 sieve (2 mm), mixed well, and proportioned for laboratory testing.

All solid materials used in the batch equilibration tests were crushed in a similar manner. Crushing to 2 mm enhances contact between the solid and liquid phases to promote short-term attainment of equilibrium in the laboratory. In the field, equilibrium will be achieved due to the long contact times between the ground water and solid materials.

Precipitator Ash

Precipitator ash was collected from the storage silo of Unit Two at the San Juan Generating Station. The unit was fully operational on the date of collection, August 11, 1983.

During normal operations, precipitator ash is loaded into trucks for disposal in the mine approximately twice a day. The loading procedure consists of fluidizing the ash in the silo with air jets located at the bottom of the silo. Once fluidized (or diffused), the ash flows by gravity into a mixer where water is added to prevent dusting during transport to the mine. After mixing, the ash is dumped into trucks and carried to the mine.

Figure 27.2.1-2 presents a simplified schematic of material flow in the San Juan Generating Station. Precipitator ash was collected at Point 1 on the diagram during truck loading. During loading, the air diffusers were on and the ash was well mixed. A five gallon polycarbonate bucket was filled with ash, sealed airtight, and shipped to Radian Corporation in Austin, Texas.

A primary concern of this study was the representativeness of the samples collected for laboratory testing. This is especially the case for the waste samples, since a principal objective of this work was to evaluate the impacts of waste disposal on the ground water. Over 99% of the waste materials, by weight, going to the mine from the plant consist of coal ash (83% precipitator ash and 17% bottom ash).

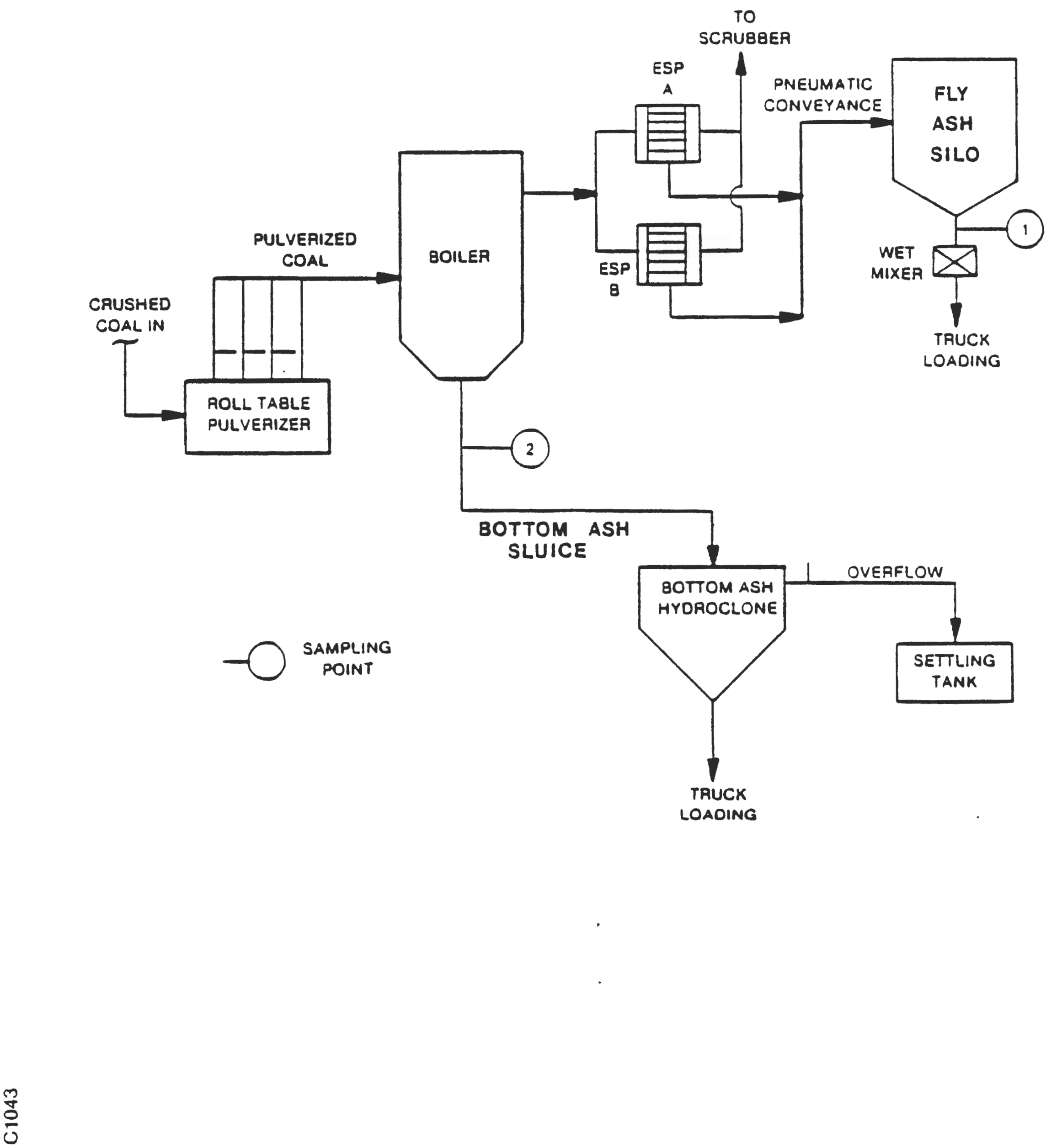


Figure 27.2.1-2. Locations of Precipitator Ash and Bottom Ash Sampling Points.

A research project conducted by Radian Corporation for the Electric Power Research Institute (EPRI, 1983) illustrates high consistency in the composition over time of the San Juan Power Plant coal ash. This study was conducted in 1980 at the San Juan Generating Station to determine the time variability of an ash stream. Samples of precipitator ash and bottom ash were collected over a five-month period and analyzed for elemental and extractable concentrations, and the results were statistically analyzed to determine variability. Figures 27.2.1-3 and 27.2.1-4 present the variability of aluminum and arsenic, respectively, over the five-month sampling period. As shown, the concentrations are essentially constant over time for these two elements. The same behavior was generally apparent for the other major and trace elements.

Bottom Ash

As coal is fired in the generating station boilers, a portion of the coal combustion residuals fall to the bottom of the boiler as slag or bottom ash. The bottom ash is sluiced from a quench tank at the bottom of the boiler to a storage hydroclone. Sources of water used to sluice the ash include recycled sluice water, cooling tower blowdown water, and supernatant return water.

Bottom ash was sampled on August 11, 1983 from the bottom of the boiler on Unit Two (Sampling Point 2 in Figure 27.2.1-2). For the purposes of the sampling efforts, a large pile of damp ash was deposited on the boiler room floor. Five random scoops from across this pile were

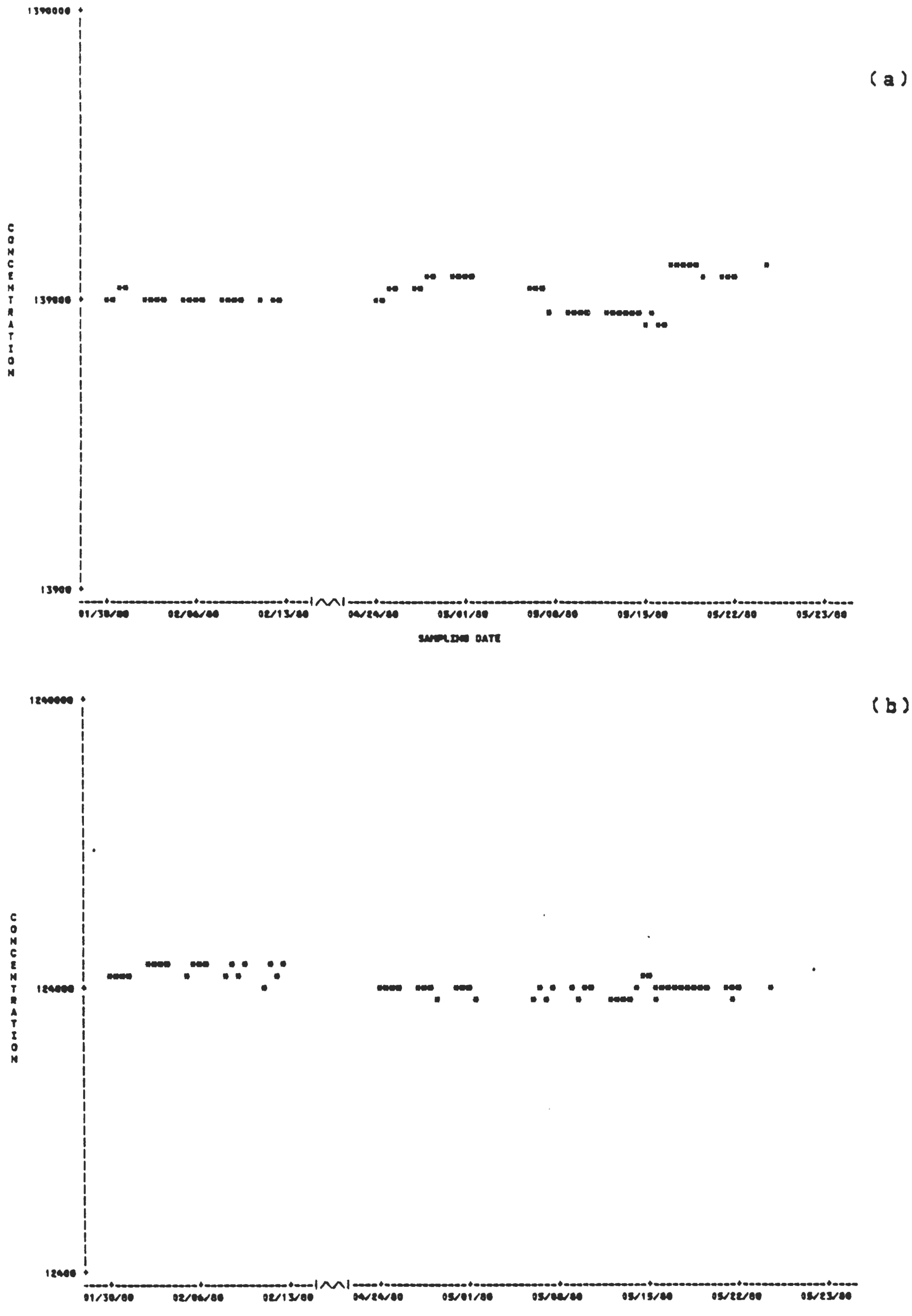
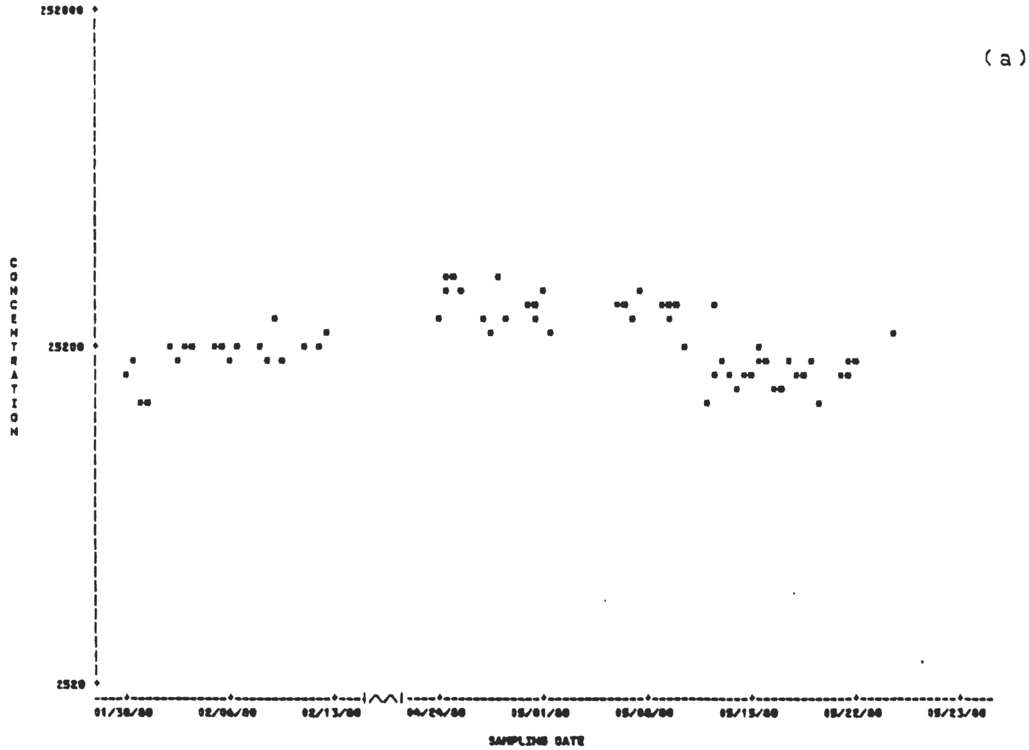


Figure 27.2.1-3. Measured Aluminum (Al) in (a) Bottom Ash and (b) Precipitator Ash Samples (ppm) from San Juan Power Plant, 1980. (SOURCE: EPRI, 1983)



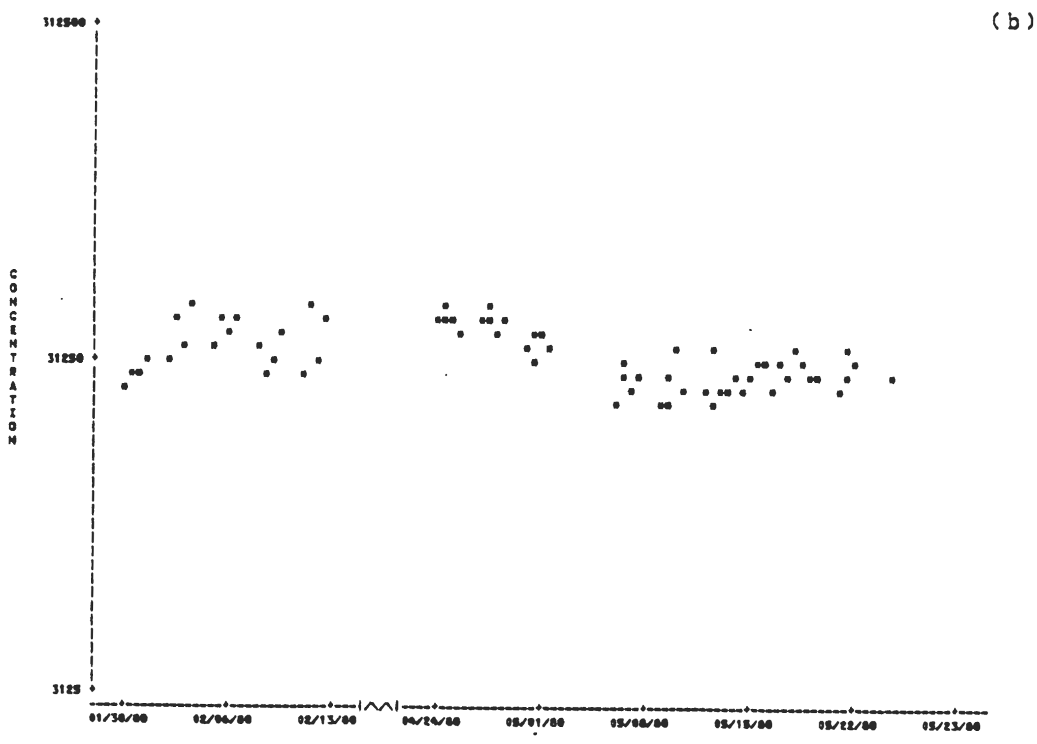


Figure 27.2.1-4. Measured Arsenic (As) in (a) Bottom Ash and (b) Precipitator Ash Samples (ppb) from San Juan Power Plant, 1980. (SOURCE: EPRI, 1983)

composited in a five-gallon polycarbonate bucket. This sample represents the "as disposed of" bottom ash.

Process Water Treatment Sludge

Residual streams from the San Juan Power Plant water treatment system are combined and neutralized with soda ash or caustic. The sludges resulting from the neutralization are dewatered in centrifuges. Two different dewatering stations exist at the plant. The south-side dewatering subsystem treats sludge from the brine concentrator for Power Blocks 1 and 2 and sludge from the SO_2 waste treatment system. Sludge flow from this subsystem is approximately 32,000 gallons per day. The north-side dewatering subsystem treats sludge from the reverse osmosis/brine concentrator for Power Blocks 3 and 4 and the sludge from the north-side neutralization system. This subsystem generates approximately 50,000 gallons of sludge per day. At present, process water treatment sludges are not disposed of in the mine.

Samples of both subsystem sludges were collected from dump trucks during loading of the centrifuges. Two-liter polyethylene bottles containing the sludge samples were sealed and shipped to Radian laboratories.

Coal Seam No. 8 Material

The material used for the attenuation study was collected from four coreholes across the mine. Figure 27.2.1-1 illustrates the locations of coreholes (SJCC wells) 12, 14, 15 and 16. The cores were sealed in plastic and shipped to Radian where samples of coal were taken from each core at approximately two foot intervals and composited. The final coal composite, weighing about 5,000 grams, was crushed to pass a No. 10 sieve (2 mm) for use in the attenuation tests.

27.2.1.2.2 Laboratory Testing

Laboratory testing of the waste and geologic materials was conducted (as opposed to obtaining estimates from the literature) in order to provide a more reliable ground-water impact assessment. As noted, laboratory testing included the following:

- RCRA classification of the composite waste (fly ash, bottom ash and neutralizer sludge in their production ratios);
- Compaction and permeability measurements on the composite wastes and spoils.
- Chemical analyses of the leachates and extracts generated; and
- Batch equilibrations.

RCRA Classification

The waste materials scheduled for mine disposal were composited according to their production ratios as shown below:

Solid Waste		Percent (Dry Weight)
Precipitator Ash		82.6
Bottom Ash		17.0
South Centrifuge Sludge		0.16
North Centrifuge Sludge		0.24
	Total	100.00

Results from whole-sample chemical analysis performed on the composited waste are presented in Table 27.2.1-3. The chemical parameters measured are the parameters regulated by the New Mexico Water Quality Control Commission. These results show that this waste is largely an aluminum and calcium based solid. This is consistent with the fact that the waste is predominantly coal ash.

The composite waste was subjected to the RCRA Extraction Procedure (EP) as described in the Federal Register, 45 (98), May 19, 1980. Table 27.2.1-4 presents the results of duplicate EP extractions. The results are well below the limits for EP Toxicity.

Compaction and Hydraulic Conductivity

The hydraulic conductivities of the waste and spoil materials under post-mining conditions must be known for the evaluation of potential water resource impacts. Following mine reclamation, these materials will be under considerable load. To simulate this load and the associated compaction/consolidation, the representative waste and spoil composites were compacted in the laboratory at optimum moisture under a standard load (ASTM D-558, "Standard Test Methods for Moisture-Density Relations

TABLE 27.2.1-3 WHOLE-SAMPLE CHEMICAL ANALYSIS OF COMPOSITE WASTE[1]

Element	Concentration µg/g (dry weight)
Arsenic	12.
Barium	630.
Cadmium	0.60
Chromium	6.3
Cyanide	< 0.02
Fluoride	14
Lead	11
Mercury	< 0.002
Nitrate (as N)	< 50
Selenium	0.54
Silver	< 0.2
Uranium	< 6
Combined radium-226 and radium-228	To be reported Oct. 25, 1983
Chloride	45
Copper	13
Iron	5,500
Manganese	130
Phenols	0.12
Sulfate	360
Zinc	13
Aluminum	11,000 (1.1%)
Boron	290
Cobalt	2.4
Molybdenum	4.9
Nickel	2.2
Calcium	20,000 (2.0%)
Sodium	1,000
Magnesium	1,100
Potassium	370
pH	
SAR	

[1]Sample includes 11.5% moisture by weight.

EP Toxicity test for heavy metals

TABLE 27.2.1-4. CHEMICAL ANALYSIS OF EP EXTRACT[1], COMPOSITE WASTE

	Concentration mg/L	
Element	Composite Waste[2]	EP Toxicity Maximum Concentration
Arsenic	<0.06	5.0
Barium	0.61	100.0
Cadmium	0.007	1.0
Chromium	0.11	5.0
Lead	<0.08	5.0
Mercury	<0.002	0.2
Selenium	<0.06	1.0
Silver	0.006	5.0

[1] EPA, 1980.

[2] Average of Duplicate EP Extractions. Composite waste consists of 82.6% fly ash, 17.0% bottom ash, 0.16% south centrifuge sludge, and 0.24% north centrifuge sludge (on a dry-weight basis).

of Soil Cement Mixtures"). The procedure consists of compacting the materials under a specified load (5.5-lb. hammer dropped from a height of 12 inches).

At a specific moisture content, the solids will obtain a maximum compacted density. At this maximum density, nearly all the voids are filled with water but the particles remain in a tightly packed state. A similar packed density should exist in the mine spoil after reclamation and saturation with ground water. It is under these conditions of maximum-compacted density that the hydraulic conductivities were measured.

Figures 27.2.1-5 and 27.2.1-6 present the moisture-density compaction curves for the composite waste and spoil, respectively. The curves show the dry density of the solids as a function of water content. The maximum dry density at optimum water content was determined to be 70.3 lbs/ft^3 for the composite waste and 99.5 lbs/ft^3 for the spoil.

The hydraulic conductivities of the waste and spoil materials were measured using a constant-head permeameter. The solids were packed into the permeameter column at the above-mentioned densities taking care that all voids remained saturated with water. A constant water head was applied to the permeameter and the rate of flow through the column was measured over time. The hydraulic conductivity was calculated from the flow rate, pressure, and permeameter constants. For the waste, a hydraulic conductivity of 2.3×10^{-7} cm/sec (6.5×10^{-4}/ft/day) was obtained, and for the spoil, less than 10^{-8} cm/sec (2.8×10^{-5} ft/day). These low hydraulic

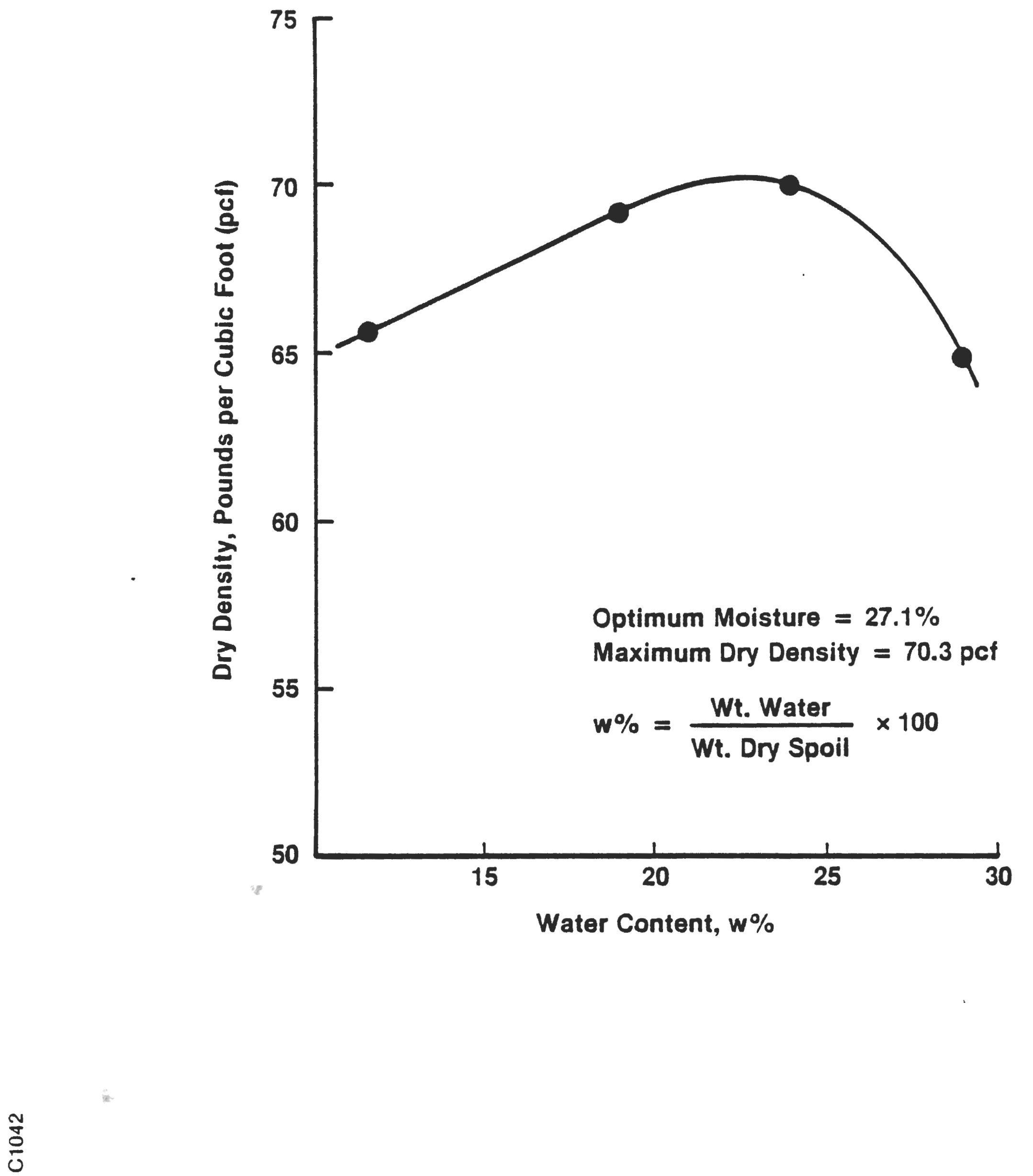


Figure 27.2.1-5. Moisture-Density Compaction Curve for Composite Waste (Waste Consisted of 82.6% Fly Ash, 17.0% Bottom Ash, 0.16% South Centrifuge Sludge and 0.24% North Centrifuge Sludge, on a Dry Weight Basis).

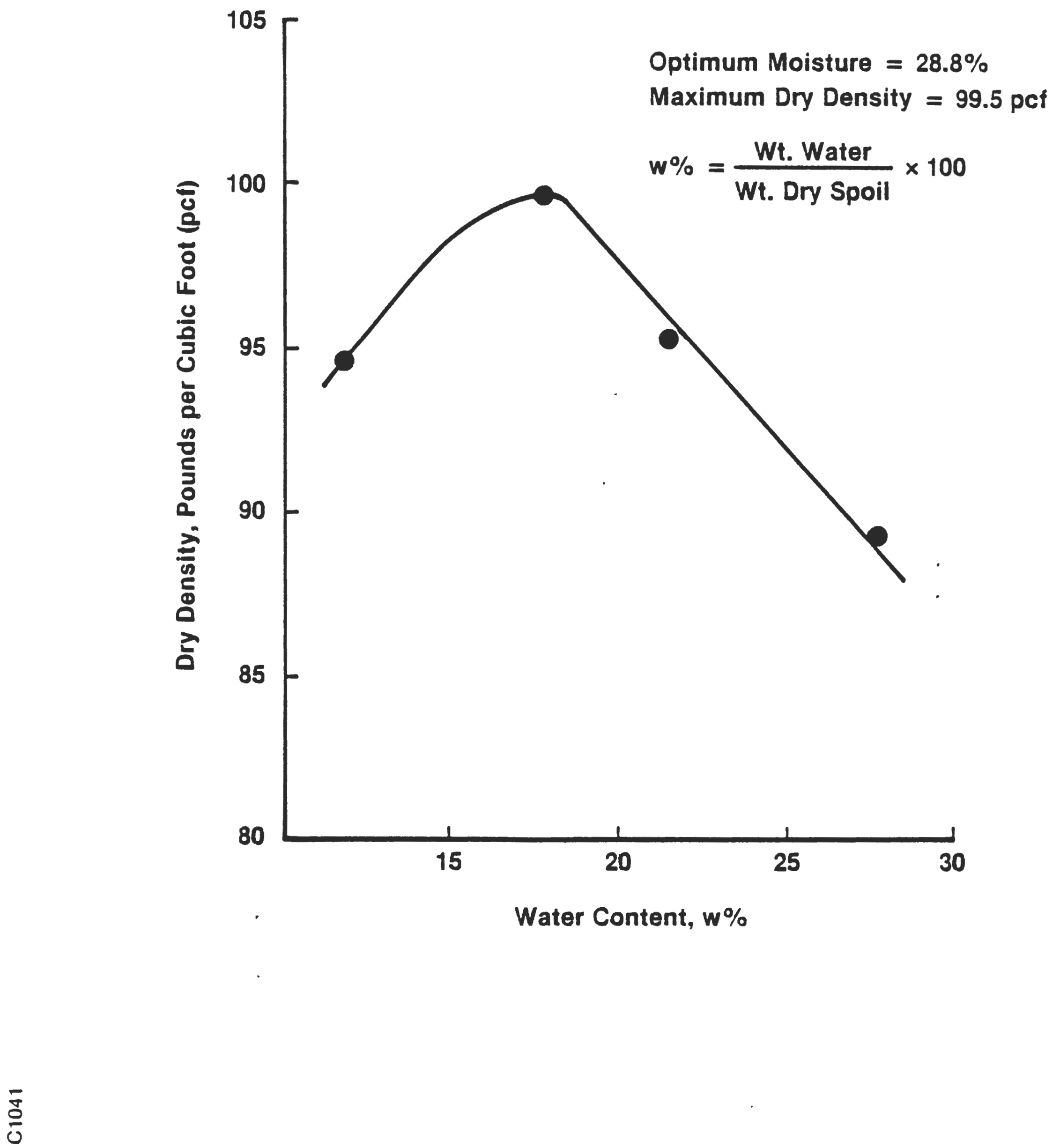


Figure 27.2.1-6. Moisture-Density Compaction Curve for Composite Spoil.

conductivities are typical of fine-grained materials, such as silts and clays.

27.2.1.2.3 Laboratory Results

Analysis of Ground Water and Leachates

Chemical quality was determined for three waters: (1) ground water collected from the water-bearing coal seam, (2) leachate generated from an equilibration of the coal seam water and the composite spoil sample, and (3) leachate generated from an equilibration of the coal seam water and a blend of the composite spoil and composite waste samples. The two equilibrations provided a comparison between leachate generated both in the absence and in the presence of the waste in the mine. The results of these analyses are given in Table 27.2.1-5.

Comparison of ground-water quality to the spoil leachate and spoil plus waste leachate shows the following:

- The spoil plus waste leachate contained the highest concentration of arsenic, barium, chromium, fluoride, total dissolved solids, pH, aluminum, boron, molybdenum, and nickel.
- The spoil leachate contained the highest concentrations of lead, silver, iron, and magnesium.
- The ground water contained the highest cyanide, chloride, manganese, zinc, calcium, and potassium concentration.

TABLE 27.2.1-5. CHEMICAL ANALYSIS OF GROUND WATER, LEACHATE, AND ATTENUATED LEACHATES[1]

Element	Concentration mg/L (except where noted)					
	Ground-Water Composite	Spoil Leachate	Attenuated Spoil Leachate	Spoil-Waste Leachate	Attenuated Spoil-Waste Leachate	Standards for Ground Water
Arsenic	<0.003	<0.003	<0.003	0.26	0.37	0.1
Barium	0.21	0.28	0.17	0.39	0.078	1.0
Cadmium	<0.002	<0.002	<0.002	<0.002	<0.002	0.01
Chromium	<0.001	<0.001	<0.001	0.006	<0.001	0.05
Cyanide	0.53	<0.02	<0.02	<0.02	<0.02	0.2
Fluoride	2.1	2.4	2.2	7.8	7.1	1.6
Lead	0.02	0.010	<0.002	<0.002	<0.002	0.05
Mercury	<0.002	<0.002	<0.002	<0.002	<0.002	0.002
Nitrate (as N)	<0.5	<0.5	<0.5	<0.5	<0.5	10.0
Selenium	<0.003	<0.003	<0.003	<0.003	<0.003	0.05
Silver	<0.002	0.006	<0.002	0.003	<0.002	0.05
Uranium	<0.06	<0.06	<0.06	<0.06	<0.06	5.0
Radium-226 (pCi/L)	<0.8	<0.8	<0.8	<0.8	<0.8	30.0 (combined)
Radium-228 (pCi/L)	<3	4.3	<3	<3	<4	

(Continued)

TABLE 27.2.1-5. CHEMICAL ANALYSIS OF GROUND WATER, LEACHATE, AND ATTENUATED LEACHATES[1] (Continued)

	Concentration mg/L (except where noted)					
Element	Ground-Water Composite	Spoil Leachate	Attenuated Spoil Leachate	Spoil-Waste Leachate	Attenuated Spoil-Waste Leachate	Standards for Ground Water
Chloride	600	580	800	540	540	250
Copper	<0.001	<0.001	<0.001	<0.001	<0.001	1.0
Iron	0.37	2.0	0.021	0.27	<0.008	1.0
Manganese	0.18	0.16	<0.001	<0.001	<0.001	0.2
Phenols	<0.005	<0.005	<0.005	<0.005	<0.005	0.005
Sulfate	1,400	1,600	2,500	1,600	1,500	600
TDS (total dissolved solids)	4,950	5,100	4,900	5,200	4,800	1,000
Zinc	0.087	0.01	0.003	0.021	0.025	10
pH in pH units	9.65 units	9.07 units	8.3 units	11.5 units	9.86 units	between 6 and 9

(Continued)

TABLE 27.2.1-5. CHEMICAL ANALYSIS OF GROUND WATER, LEACHATE, AND ATTENUATED LEACHATES[1] (Continued)

	Concentration mg/L (except where noted)					
Element	Ground-Water Composite	Spoil Leachate	Attenuated Spoil Leachate	Spoil-Waste Leachate	Attenuated Spoil-Waste Leachate	Standards for Ground Water
Aluminum	<0.05	2.2	<0.050	14.	0.11	5.0
Boron	<0.009	0.44	0.89	7.0	6.2	0.75
Cobalt	<0.006	<0.006	<0.006	<0.006	<0.006	0.05
Molybdenum	<0.002	0.027	0.036	0.36	0.36	1.0
Nickel	0.004	0.006	0.006	0.008	0.010	0.2
Calcium	10.	3.5	3.4	4.2	1.4	NA
Sodium	1,700.	1,700.	1,650.	1,700.	1,650.	NA
Magnesium	2.3	2.4	3.4	<0.034	<0.034	NA
Potassium	12	11	6.6	11	5.2	NA

[1]These values represent the average of duplicate sample analyses. In the case of the batch leachings and attenuations, this includes duplication of the batch equilibration steps.

NA - Not Applicable.

note —

- Spoil leachates and ground water contained about the same amount of sulfate. The ground water, spoil leachate, and spoil-plus-waste leachate contained the same sodium concentration.

- All three liquids--ground water, spoil-plus-waste leachates, and spoil leachate--contained concentrations less than instrumental detection limits of cadmium, mercury, nitrate, selenium, uranium, copper, phenols, and cobalt.

Results were compared to New Mexico Water Quality Control Commission Standards for ground water. In the spoil-plus-waste leachates arsenic and boron concentrations exceeded the allowable limits. The fluoride, chloride, and pH standards were exceeded by coal seam ground water, the spoil leachate, and the spoil-plus-waste leachate.

Analysis of Attenuated Leachates

Once spoil/waste leachate enters the water bearing coal seam, the dissolved constitutents will migrate with the ground water. However, chemical and physical interactions between the constituents in the ground water and the coal will result in the retardation or attenuation of the dissolved constituents relative to the bulk movement or average velocity of the ground water. This attenuation will modify the overall impact of the mining and waste disposal operations on the ground-water quality. The following batch equilibrations were performed to evaluate the attenuation potential of the coal seam.

1. Equilibration of the spoil leachate with the coal from the water bearing coal seam.

2. Equlibration of the spoil-plus-water leachate with the coal.

The results of the batch equilibration testing provided both qualitative and quantitative data for the assessment of potential impacts. Distribution coefficients derived from batch testing were used to estimate retardation rates and to qualitatively describe the attenuation of the coal seam. Analytical results are presented in Table 27.2.1-5.

Qualitatively, these results show the following attenuation or mobilization (in the coal) of chemical contaminants in the spoil-plus-waste leachate and spoil leachate:

- Concentrations of fluoride, silver, iron, total dissolved solids, pH, aluminum, calcium, sodium, and potassium were attenuated by the coal in both spoil-plus-waste leachate and spoil leachate.
- Concentrations of barium, mercury, iron, manganese, and zinc were attenuated by the coal for the spoil leachate only.
- Concentrations of sulfate and boron were attenuated by the coal for the spoil-plus-waste leachate only.
- The coal mobilized (increased concentrations of chloride, sulfate, boron, molybdenum, and magnesium over the spoil leachate.
- The coal mobilized concentrations of arsenic, barium, zinc, and nickel over the spoil-plus-waste leachate.

Compared to guidelines for ground water in New Mexico, both of the attenuated leachates exceeded the allowable limits for concentrations of boron, chloride, and fluoride. The attenuated spoil-plus-waste leachate also exceeded the guidelines set for pH. It should be noted that the ground water also exceeded limits for fluoride, chloride, and pH.

Migratory Retardation Properties: Attenuation of Potential Ground-Water Contaminants

Direct comparison of leachate data indicates that the following waste species are predicted to be attenuated in varying degrees: aluminum, iron, fluoride, barium, calcium, magnesium, manganese, nickel, chromium, chloride, potassium, sodium, pH, silver, boron, sulfate, and total dissolved solids. To evaluate the degree of attenuation, distribution coefficients were calculated and used to estimate relative migration rates. These distribution coefficients and relative migration rates are approximations based on laboratory performance and stated assumptions. They represent state-of-the-art formulations for describing geochemical attenuation in the subsurface environment. Although various field conditions, such as anisotrophy in the water-bearing seam, may affect actual attenuation, the treatment presented here indicates the relative attenuations that can be expected in the field.

Concentrations of species in batch equilibrations were used to estimate single-point solid-liquid distribution coefficients for attenuated chemical species as an indication of the attenuation potential of the coal seam. The distribution coefficient is defined as the ratio of the concentration in the solid phase to the concentration in the liquid phase after equilibration. Solid phase concentrations were estimated by subtracting the final, equilibrated, liquid phase concentration from the initial liquid phase concentration, assuming the difference remains in the coal. For each chemical species and for each set of liquid phase concentrations:

$$K_D = \frac{V(A-B)\ (1000)}{(P)\ (B)}$$

where,

K_D = distribution coefficient (mL/g);

V = volume of contaminated water used in equilibration including coal moisture (L);

A = concentration in (filtered) liquid before coal contact (μg/L);

P = dry weight of coal (g); and

B = concentration in liquid phase after equilibration (μg/L).

The calculated distribution coefficients between the solid (coal) and liquid phases (waste leachate) were used to calculate a relative migration rate for each chemical species.

Relative Migration Rates

The concept used in the laboratory program was based on infiltration followed by migration, in which ground water passes through spoil and waste and leaches trace amounts of chemical species. Then, the water carries the chemical species into the geologic formation surrounding the waste, where constituents in the water react with, in this case, the coal seam. If chemical species are leached freely from the waste, it is their reactions with the coal that determine their migratory behavior. This concept was mathematically modeled using simplifying assumptions concerning the chemical reactions of coal with waste leachate to calculate the migration by fluid flow in the coal with defined velocities. The following simplifying assumptions were used in this model:

- The contaminant/coal reactions are instantaneous and maintain local equilibrium;
- The exchange reactions of the waste constituents between coal and solution are reversible;
- The coal formation is a continuous homogeneous medium; and
- The concentration of each chemical species is sufficiently low that each species reacts independently and does not affect macroscopic properties of the water.

This model is described in more detail in the literature (Seitz, 1979). Using these assumptions, each chemical species is expected to migrate through the coal with a well-defined velocity. As a contamination front moves through the coal, it widens and a Gaussian curve is assumed. This relative velocity can then be calculated using the following equation:

$$V_C/V_W = \frac{1}{1 + K_D\ \delta/\varepsilon}$$

where

V_C = velocity of the peak of a contaminant band;

V_W = velocity of the waterfront;

K_D = distribution coefficient;

δ = bulk density of the coal; and

ε = the porosity of the coal.

Bulk density of the coal was calculated from the laboratory measured coal mass and aqueous displacement volume and porosity value of 0.05 was used based on the value of specific yield used for the pit inflow modeling. A summary of the calculated relative migration rates is given in Table 27.2.1-6.

TABLE 27.2.1-6. RELATIVE MIGRATION RATES OF ATTENUATED SPECIES SPOIL/WASTE RETARDATION FACTORS (V_C/V_W)

10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}
B	Cl	Ba	Fe	Al
SO_4	K	Ca	F	
TDS	Na	Mg		
	Ag	Mn		
		Ni		
		Cr		

These results indicate that aluminum will travel through the coal seam at a factor of 10^{-5} slower than water; in other words, aluminum velocity is highly retarded compared to the water front velocity. Iron and fluoride are also highly retarded (retardation factor = 10^{-4}). Groups of chemical species having similar relative migration rates shared the same numerical valence state. Generally, species with a retardation factor of 10^{-2} are in the +1 or -1 valence state. Barium, calcium, and magnesium (+2 valence state) have a retardation factor of 10^{-3}. Also in the 10^{-3} group fall manganese, nickel, and chromium (several multivalent states possible).

Relative migration rates allow comparison of the degree of predicted attenuation. While these predictions are based on scientifically tenable concepts, they should not be construed as precise values which can be applied directly to indicate field performance on an absolute scale. Actual field attenuation may involve mechanisms that are independent site-specific factors possibly not accounted for in this simplified model.

27.2.1.2.4 Quality Assurance

Quality assurance concentrated on the following aspects of laboratory testing: 1) sampling; 2) laboratory procedures; and 3) chemical analysis. Sampling quality was assured by obtaining samples which were as representative as possible of a particular material population. Several grab samples were collected and composited to increase sample representativeness. For the power plant waste streams, the question arises concerning sample variability over time. However, as noted in Section 27.2.1.2.1, precipitator ash, which constitutes the bulk of the waste stream, has a very constant elemental composition.

Laboratory equilibrations were conducted in duplicate as a quality control check. Each batch leaching and batch attenuation concentration value represents the average of duplicate tests. This duplication included the batch equilibrations as well as the chemical analysis step.

Analytical quality control consisted of tracking and documenting the precision and accuracy of all chemical analyses. Every tenth sample analyzed was a quality control standard. If the analytical results of the standard did not agree with the expected value, then steps were taken to correct the problem. Also, every tenth sample was a sample spike. The analytical recovery of the spiked sample was monitored, and if recovery fell outside of accepted limits, steps were taken to correct the problem.

27.2.1.3 Evaluation of Potential Ground-Water Leachate Transport

To evaluate potential chemical impacts to ground-water resources and receptor points resulting from mining and waste disposal activities, the potential for subsurface leachate migration was evaluated. This evaluation was based on data obtained from numerous literature sources and from site-specific data. Data obtained from literature sources were used to supplement and check site-specific hydrogeologic data.

Literature sources for this study included published and unpublished reports, papers, and data authored or developed by several state and federal natural resource management agencies. Reports published by private consultants and academic institutions were also utilized. Site-specific data were developed by SJCC through drilling, monitor/piezometer well installations, pump testing, and pit inflow modeling efforts, as described in Chapter 12. Additional data were provided from past geological investigations conducted by SJCC and from observations made by SJCC staff during the day-to-day operation of the mine.

The collected data were used to describe and evaluate the geologic setting of the mine and the occurrence of ground water at the mine with respect to mining operations and potential ground-water quality impacts. Significant water-bearing units potentially affected by mining operations were identified. Estimates of ground-water flow velocities, projected travel times, and volume of ground-water flow were calculated for the evaluation of potential leachate transport. These results were considered with respect to the results of laboratory study determinations of leachate quality and leachate-matrix chemical interactions for the evaluation of potential leachate transport.

27.2.1.3.1 Geologic Setting

The geologic setting of the San Juan Mine has been discussed in detail in Chapter 11. The geologic setting of the mine is also described here but only with respect to the occurrence, quality, and movement of ground water in and about the mine.

The San Juan Mine is located on the western flank of the San Juan Basin, a Laramide structural depression lying along the eastern border of the Colorado Plateau (Fassett, 1971). Upper Cretaceous sedimentary rocks at the mine dip gently to the east and southeast (toward the center of the basin) at approximately 1.5 to 3 degrees (Shumaker, 1971).

Stratigraphic units which occur at the surface or at moderate depths in the vicinity of the mine include (in the order of decreasing age) the Lewis Shale, Pictured Cliffs Sandstone, Fruitland Formation, and the Kirtland Shale, all Upper Cretaceous sedimentary deposits. In addition, Quaternary alluvial fill mantles the outcrop areas of these units (Stone, 1983) where significant drainageways exist (see Chapter 12.8).

Because of the varying lithologic properties of these units and their presence at ground surface or at moderate depths in the vicinity of the mine, they are of concern to the hydrogeologic setting of the mine. Each unit is discussed below.

Lewis Shale

The Lewis Shale is a light to dark-gray and black shale with interbeds of sandstone, sandy to silty limestones, calcareous concretions and bentonite. Bentonite occurs mainly as the Huerfanito Bentonite Bed within the central portion of the unit. The Lewis Shale is stratigraphically the highest marine shale unit in the San Juan Basin.

Although information pertaining to the Lewis Shale below the mine is limited, it is estimated that the top of the unit lies 300 to 600 feet below ground surface. Borehole logs of spontaneous potential and resistivity for the J.R. Pickett 1 Fruitland-Amarillo and Sunray Mid-Continent Oil 1 Federal K wells which are located approximately 5 miles to the southeast and 2 miles east of the mine lease area, respectively, include the Lewis

Shale (Stone, 1983). Interpretations of these logs and related cross-sections indicate that the Lewis Shale is over 800 feet in thickness immediately east and downdip of the mine lease area.

The Lewis Shale outcrop area lies approximately 2 miles to the west of the southern section of the mine lease and is nearly adjacent to the extreme northwestern corner of the mine lease (see Exhibit 11.1-1). An analysis of the configuration and extent of the outcrop area of the Lewis Shale and an east-west cross-section, in the literature (Stone, 1983) reveals that the Lewis Shale thins toward the west to the outcrop. It is estimated that this formation is 500 feet thick beneath the mine lease. In addition, it is apparent that the eastward dip of this formation gradually increases beneath the mine in the direction of the outcrop and the area of the Hogback Monocline.

Because the Lewis Shale is relatively thick and because it primarily consists of low-permeability materials, it probably functions as an aquitard in the mine area. Thus, the Lewis Shale should effectively isolate water-bearing units which underlie it. These underlying units appear to be of little concern to this study because of the large depths at which these units occur, the poor quality of water in these units, and their apparent low productivity. These conclusions were also drawn in a similar yet separate study conducted for the Navajo Mine, located just south of the San Juan Mine (SAI, 1979). In light of the apparent properties of the Lewis Shale and its stratigraphic position, it is the lowest unit considered in this study.

Pictured Cliffs Sandstone

The Pictured Cliffs Sandstone conformably overlies the Lewis Shale in the area of the San Juan Mine. The contact between the Pictured Cliffs and the Lewis Shale is reported as being gradational in most of the San Juan Basin (Stone, 1983) with the shale beds of the Lewis intertonguing with the sandstone beds of the Pictured Cliffs. The Pictured Cliffs Sandstone is the highest marine sandstone in the basin and is regionally described as being composed of sandstones and thin interbeds of shale. Sandstones of the formation generally consist of medium to fine-grained, well-sorted sands with varying degrees of cementing with calcite, clay, silica, and iron oxide (Fassett, 1971). The upper two-thirds of the formation usually consist of massive layers of sandstone and relatively few interbeds of shale, while the lower one-third of the formation contains sandstone and shale.

Outcrop areas of the Pictured Cliffs occur along the western border of the mine lease as shown in Exhibit 11.1-11. The Pictured Cliffs is also exposed along the northern edge of the San Juan River Valley, which is located just south of the mine area.

Based on past drilling activities at the San Juan mine, the Pictured Cliffs Sandstone averages 120 feet in thickness below the mine and surrounding areas. The top of the formation generally occurs 100 to 300 feet below ground surface in the mine area. Mine drilling records and outcrops of the Pictured Cliffs in the vicinity of the mine give evidence that this unit dips more gently than the underlying Lewis Shale in this area. The Pictured Cliffs generally dips to the east and southeast at 2 degrees with the dip increasing somewhat in the vicinity of the Hogback Monocline.

Fruitland Formation

The non-marine Fruitland Formation is in conformable contact with the underlying Pictured Cliffs Sandstone. The Fruitland Formation consists of a complex sequence of interbedded siltstone, sandstone, shale carbonaceous shale, carbonaceous sandstone, coal, and (in the lower sections of the formation) thin beds of limestone (Niemczk, 1980). Sandstone beds within the Fruitland exhibit calcite, clay, and iron cementing to varying degrees (Fassett, 1971). Generally, the various lithologic units of the Fruitland are laterally discontinuous and tend to pinch out (Fassett, 1971). Two main coal seams, referred to as Coal Seams No. 8 and 9, exist at the mine and are essentially continuous throughout the lease area.

The lower coal seam, Seam No. 8, is generally within 10 to 20 feet of the top of the Pictured Cliffs Sandstone (see Chapter 11.0). The lower coal seam and the Pictured Cliffs Sandstone are separated by 10 to 20 feet of shale with siltstone. Coal Seam No. 8 is the most laterally consistent and economically important seam within the mine area. The thickness and composition of the lower coal seam varies somewhat. Thinning of the seam to approximately 2 feet of total thickness occurs in the central area of the mine lease. The average thickness of the lower seam is about 14 feet within the mine. Thin interbeds of shale and siltstone are found within the seam in the area of the mine (Shomaker, 1971).

The upper coal seam, referred to as Seam No. 9, lies an average of 110 feet above the lower coal seam. Interbedded layers of siltstone, sandstone, shale, carbonaceous shale, and carbonaceous sandstone lie between the two coal seams and above the upper coal seam. Through mining activities at the San Juan Mine, the average thickness of the upper coal seam is estimated to be 4.5 feet in the mine. The thickness of this seam varies considerably within the lease area with thinning to less than two feet.

The Fruitland Formation crops out within almost the entire mine lease area (see Exhibit 11.1-1) and has a variable thickness, as a function of topography. Regionally, the thickness of the Fruitland Formation is reported to vary between 200 and 300 feet (Stone, 1983). Geophysical logs of the Sunray Mid-Continental Oil Well, located just east of the outcrop area and the mine, indicate that the Fruitland Formation is approximately 150 feet thick in the mine area. The dip of the Fruitland Formation within the mine area averages 2 degrees to the east-southeast.

Kirtland Shale

The Kirtland Shale conformably overlies the Fruitland Formation in the vicinity of the mine. This non-marine sedimentary deposit is usually considered as three distinct units which are referred to (in ascending order) as the Lower Shale Member, Farmington Sandstone Member, and Upper Shale Member. In the area of the San Juan Mine, the Kirtland Shale reportedly consists primarily of shale with irregular abundances of soft sandstone and siltstone beds (Neimczyk, 1980).

Regionally, the Lower Shale Member of the Kirtland is composed mainly of shale with a few interbeds of thin sandstone and siltstone. The lower contact of the Kirtland Shale is the subject of some uncertainty but is often considered to be the top of the upper coal seam (Seam No. 9) in the Fruitland Formation (Fassett, 1971). The middle unit, the Farmington Sandstone, contains sandstone beds interbedded with shale and medium to fine-grained sandstone. The Upper Shale Member consists of similar sandstone and shales (Molenaar, 1977).

Regionally, the Lower Shale Member of the Kirtland is 271 to 1031 feet thick. The thickness of the Farmington Sandstone Member and Upper Shale Member vary from 20 to 480 and 12 to 475, respectively. An analysis of geophysical well logs in the literature (Stone, 1983) in the vicinity of the mine reveals that the Lower Shale Member of the Kirtland is approximately 400 feet thick. The Farmington Sandstone and Upper Shale Member have a combined thickness of about 800 feet in the area of the mine.

The Kirtland Shale crops out just downdip of the mine with the outcrop area being much wider than those of the aforementioned units (see Exhibit 11.1-1). As with the Fruitland Formation, dip appears to average about 2 degrees to the east and southeast.

The Kirtland Formation will remain essentially undisturbed by planned mining operations. Because this unit directly overlies the Fruitland Formation and because it is composed primarily of low-permeability materials, it probably acts as an upward barrier to ground-water flow in the area of the mine and is thus the highest bedrock unit to be considered in this study.

Quaternary Alluvial Fill

Quaternary alluvium disconformably mantles the Late-Cretaceous bedrock units which crop out in the area of the mine. Within the mine lease, the most significant deposits of alluvium occur along the Westwater and Shumway arroyos. More extensive deposits of alluvium are found just south of the mine in the San Juan River Valley.

The alluvium generally consists of poorly sorted mixtures of cobbles gravel, sand, silt, and clay depending on the positions of the deposits and their sources. Alluvium in the San Juan River valley and its tributaries reportedly does not exceed 100 feet in thickness (Stone, 1983). A maximum thickness of 80 feet for the San Juan River Valley alluvium has been reported for the area near Farmington (Rapp, 1959). Significantly lower thicknesses of alluvium are encountered in the Shumway and Westwater arroyos in the lease area with thickness decreasing upstream (SJCC, 1981).

27.2.1.3.2 Occurrence and Nature of Ground-Water Encountered at the San Juan Mine

Based on drilling and excavation activities conducted by SJCC and the previous owner, Western Coal Company (WCC), only the Quaternary Alluvium, the No. 8 Coal Seam of the Fruitland Formation, and the Pictured Cliffs Sandstone bear water in the mine area. The Lewis Shale probably also contains limited quantities of water but because of its depth at the mine and its lithologic composition it has not been the subject of drilling investigations. Isolated occurrences of perched water were found just above the No. 9 Coal Seam (upper seam), as discussed in Chapter 12.

In an effort to obtain information on ground-water conditions at the mine, several monitor/piezometer wells were installed by SJCC, Metric Corporation, and WCC. The locations of the wells considered by SJCC as being useful for data collection are illustrated in Figure 27.2.1-7. Of wells completed under WCC ownership of the mine, only two wells completed in the Pictured Cliffs Sandstone (Wells A and B) and three wells completed in the Quarternary Alluvium (Wells D, E, and L) were found by SJCC to be adequate for data collection purposes. For the purposes of this study, 16 monitor wells were completed by SJCC in the No. 8 Coal Seam of the Fruitland Formation throughout the lease area. Drilling and well completion procedures used by SJCC are discussed in Chapter 12.

Water level data determinations from the mine area monitor/piezometer wells are discussed in Chapter 12. Water quality determinations for

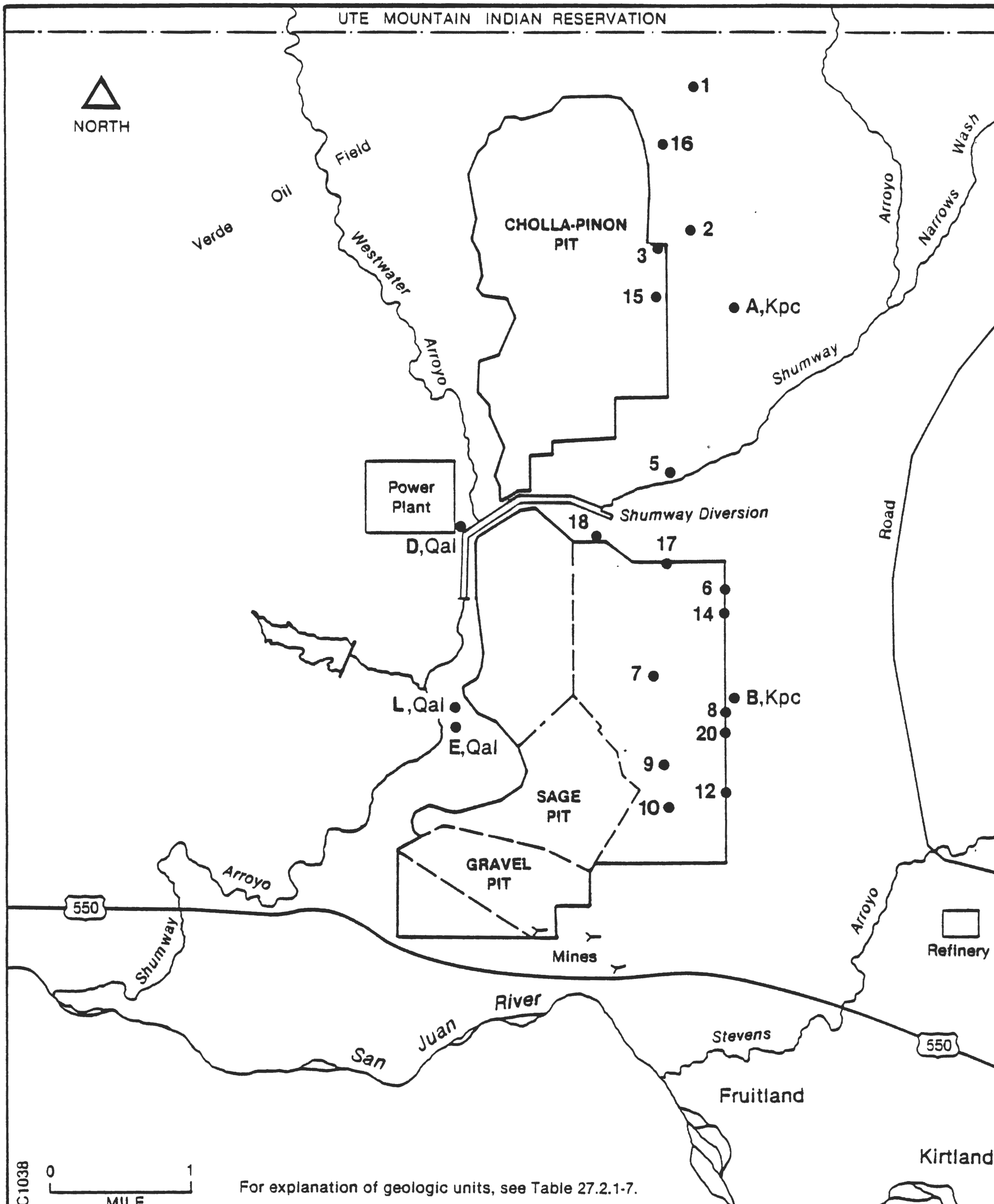


Figure 27.2.1-7. Locations of SJCC Monitor/Piezometer Wells Used for Collecting Ground Water Data.

samples collected by SJCC and WCC are also presented in Chapter 12. Analytical results from the sampling and analysis of ground water from the Coal Seam No. 8 monitor wells by Radian Corporation are listed in Table 27.2.1-5.

27.2.1.3.3 <u>Potential Migration of Waste/Spoil Leachate in Ground Water</u>

During mining operations, all strata overlying Coal Seam No. 8 are stripped to expose the coal for mining. Where economic qualities of Coal Seam No. 9 are encountered, it too is mined out. As mining operations proceed, each cut is successively backfilled with spoil and power plant ash wastes for eventual contemporanous reclamation.

The No. 8 Coal Seam, referred to as the "Main Coal Seam" of the Fruitland Formation is the only laterally extensive water-bearing unit to be directly disturbed by mining operations. During mining operations, each successive open cut will serve as a source of significant drawdown to the main coal seam. The layer of shale separating the bottom of the main coal seam and the Pictured Cliffs Sandstone should serve to isolate ground water in the Pictured Cliffs from mining activities, it is not significantly disturbed. To date, no noticeable upward seepage through the shale or significant disruption of the mine floor (shale layer) has been observed in the pits which are significantly below static levels in the Pictured Cliffs. In the area of the San Juan Mine, the Pictured Cliffs Sandstone was found to yield very small quantities of poor quality water. It is doubtful that leachate will enter the Pictured Cliffs Sandstone and should it occur, the potential for the transport of leachate and significant degradation of water quality in this unit is assumed to be small.

Because the main coal seam will be disrupted by mining activities and wastes and spoil materials placed in the reclaimed mine areas will directly abut the coal at the mine cut limits, the coal seam is the water-bearing unit of principal concern with respect to potential ground-water quality impacts of mining.

Present Flow Conditions in Coal Seam No. 8

In order to evaluate the potential effects of the mine spoil/power plant ash wastes on ground water in the main coal seam, the characteristics of flow in this unit have been determined. Ground-water flow in the main coal seam was determined from water level data obtained from a system of 15 monitor/piezometer wells installed by SJCC in the main coal seam during the summer of 1983. From these data a potentiometric map for the main coal seam was constructed by SJCC as shown in Exhibit 12-1. A small-scale rendition of this map is included here as Figure 27.2.1-8.

Based on an analysis of the map of the potentiometric surface of the main coal seam, ground water in the coal seam occurs primarily under confined conditions in the mine area. Unconfined or water-table conditions occur in a limited area along the northwestern border of the mine near the coal outcrop area.

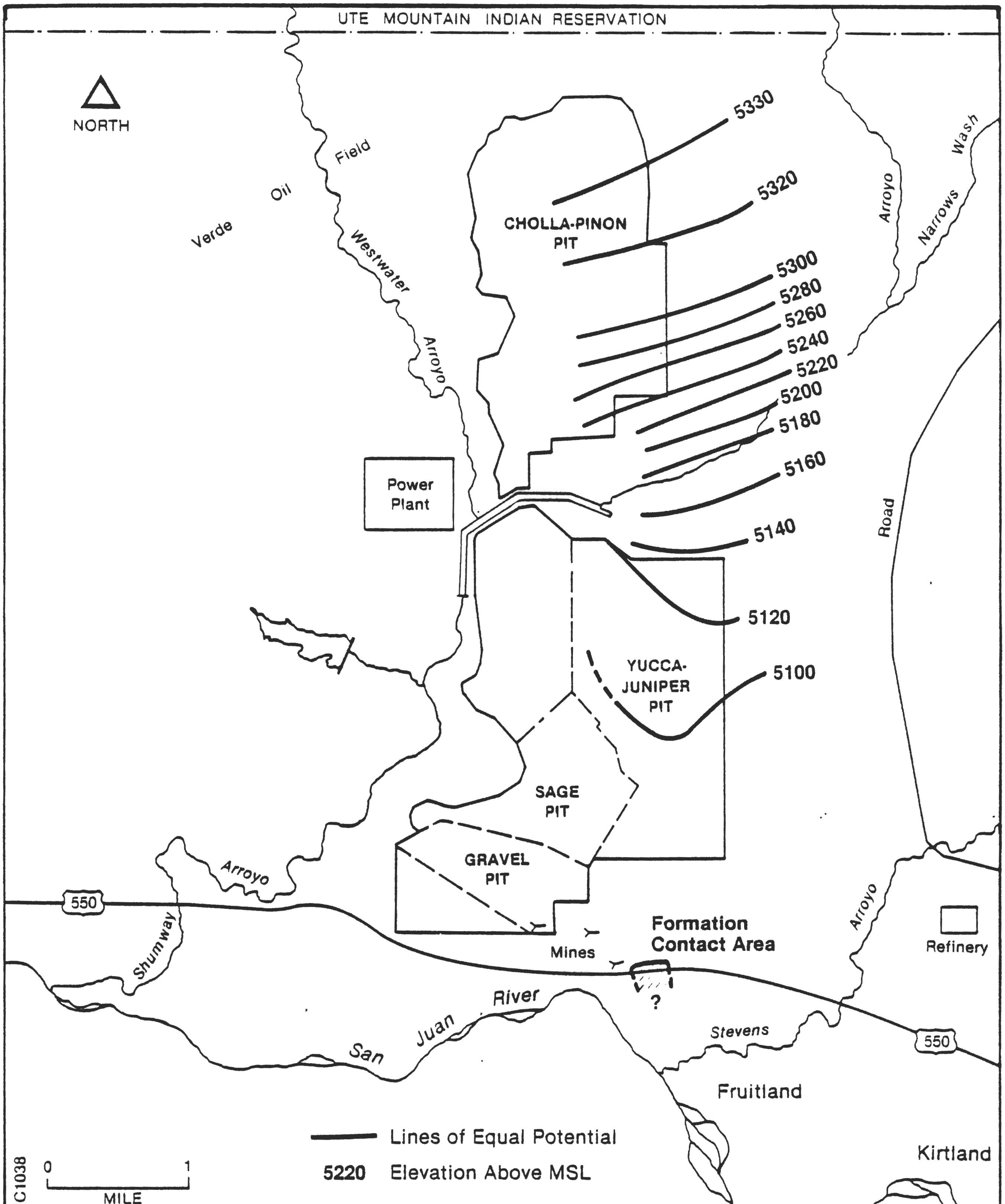


Figure 27.2.1-8. Potentiometric Map of Coal Seam No. 8 (from Exhibit 12).

In the northern and central areas of the mine, ground-water flow appears to be primarily to the southeast, toward the San Juan River Valley. In the southern section of the mine, the general direction of flow appears to be to the southwest under the partial influence of mining activities in the Yucca-Juniper Pit.

Based on the interpretation of the direction of flow in Coal Seam No. 8, the outcrop area along the northwestern border of the mine appears to be the chief area of local recharge. In the central and southern areas of the mine, limited amounts of recharge to the coal seam probably occur where significant intermittent drainageways such as the Westwater and Shumway Arroyos cross coal outcrops. Because of the highly intermittent nature of these drainageways (Stone, 1983) and the limited extent of alluvium encountered in the channels, recharge received from intermittent flows in these channels is probably very small.

The mine is located in an area which is climatologically classified as arid. Annual rainfall averages 4 to 6 inches in the area of the mine (Neimceyk, 1980) and occurs primarily during the summer months as local, and often intense, thunderstorms (Stone, 1983). Average annual Class A pan evaporation rate of 67.37 inches is reported for a station located about 3 miles northeast of Farmington, New Mexico. The highest average monthly evaporation rates occur in the summer (Stone, 1983). Based on these data, the potential for the direct infiltration of rainfall as recharge to the coal seam appears to be very low, except in areas of concentrated runoff such as the Shumway and Westwater Arroyos.

Major local discharge points for the main coal seam appear to be 1) the open mine cuts of the Sage Pit in the southern section of the mine, 2) the exposure of the seam outcrop along the San Juan River Valley, and 3) the contact of the coal seam with the San Juan River Valley fill. Discharge from the main coal seam to the open areas of the Sage Pit is evidenced by the orientation of equipotential lines in the coal seam in the southerly area of the mine (see Figure 27.2.1-8). Discharge to the open cuts appears to be low based on the observation that the open pits and coal seam exposures are essentially dry during mining, despite the fact that the exposures are significantly below area potentiometric levels.

Although the open pits of the mine apparently intercept most of the ground water which presently flows across the site, some water may reach the San Juan River Valley. Outcrops of the main coal seam along the San Juan River Valley occur at elevations below water levels in the coal seam to the north. These exposures probably serve as a major discharge point for the coal seam. As the coal seam dips to the east and southeast, towards Farmington, New Mexico, it also contacts the Quaternary alluvial fill of the San Juan River Valley. It is expected that discharge from the coal seam to the alluvium and ultimately the San Juan River occurs just south of the mine at the formational contact.

At present, no significant seeps or springs have been observed along the exposures of the main coal seam in the San Juan River Valley. This may be due to the drawdown induced by open cuts in the Sage Pit. However, observations* made during mining indicate ground water flow from the coal seam exposures to the pits is extremely low.

Discharge from the main coal seam may also occur as leakage to the units which are above or below the Fruitland Formation. Because of the significant thickness of shale, mudstone and siltstone which overly the coal seam as the upper deposits of the Fruitland Formation and the lower shale member of the Kirtland Shale, upward leakage through these units is probably very small, even significantly downdip from the mine. The layer of shale below the main coal seam probably serves to restrict interflow between the coal seam and the Pictured Cliffs Sandstone. This is supported by observations made during mining as discussed earlier. Potential discharges of coal seam water to the Pictured Cliffs would be essentially limited from further downward migration by the extensive thickness of shale and other low permeability materials in the Lewis Shale.

Structural Effects on Ground Water Flow

Extensive exploration drilling by SJCC in the mine area has revealed information on local structural features in the coal seam and associated strata. Exploratory methods used for the analysis of local structural features at the San Juan mine are discussed in Chapter 12.

Several small, localized warps in the strata, which are caused by depositional factors, were found to locally increase the dip of the strata to 4 or 5 degrees. In addition, the dip of the strata increase slightly to 4 or 5 degrees near the northern lease boundary under the influence of the Hogback Monocline. A scissor-type fault which causes a displacement of the coal seam of as much as 40 feet was found in the southern section of the mine. The fault was determined to truncate within the mine lease and is considered to be a barrier to ground water flow.

Other small-scale faults and structures were discovered in the mine lease area* as a result of mining activities and drilling operations. The effect of the small-scale structural warps and faults in the coal seam on the modification of vertical permeability and the hydraulic interconnection between strata at the mine is not known. Because strata in the area of the mine have not been intensively folded and faults in the strata tend to be limited in displacement and extent, vertical permeability between strata is probably limited by the lithologic composition of the strata. The fact that ground water was found at high pressure in the main coal seam, and that adjacent units do not bear water during drilling supports this assertion. A more detailed analysis of the hydrogeologic effects of the various minor structural features found at the mine is presented in Chapter 12.

Post-Mining Flow Conditions in Coal Seam No. 8

Following the completion of mining activities in the northern and southerly sections of the mine (in the years 2004 and 2016, respectively), the last cuts will be backfilled with mine spoil and (presumably) ash wastes. With the absence of open cuts, the filled mine blocks will begin to receive significant contributions of ground water from the coal seam contacts at the periphery of the reclaimed areas and the alluvial subcrops to the west. Through pit inflow modeling studies it was estimated that water levels in the backfilled mine blocks would rise at an approximate rate of 1 foot per year as a result of inflow received from the main coal seam. The methodologies and results of the pit inflow evaluations are described in Chapter 27.2.2.

As water levels in the reclaimed mine areas rise with time, the pits will receive successively less inflow from the coal seam. After the water levels in the coal seam have sufficiently recovered, the coal will begin to receive leachate from the spoil/ash waste as ground water flows through the mine blocks. Rising water levels in the mine area will cause water within the reclaimed mine blocks to abut the other interlayers of the Fruitland Formation at the periphery of the mine. Because of the composition of these layers, infiltration into these layers is expected to be minimal.

After significant recovery has occurred in the coal, the area discharge and recharge points to the north and south of the mine should serve as the principal controls to flow in the Fruitland Coal Seam in the absence of drawdown induced by the mine cuts. Based upon laboratory determinations of the hydraulic conductivity or permeability of the spoil and ash materials (see 27.2.1.2.2), the backfilled ash and spoil will have permeabilities on the order of 6.5×10^{-4} ft/day (2.3×10^{-7} cm/sec) and 2.8×10^{-5} ft/day (10^{-8} cm/sec), respectively. Given that the geometric mean permeability of the coal seam was determined to be 0.0119 ft/day (see Chapter 12), the composite backfilled materials should be less permeable than the coal if they are significantly compacted. As a result, ground-water flow through the mined-out areas should be roughly equivalent or less than that which occurred in these areas before mining. Due to the probable absence of a confining layer, water table conditions will undoubtedly be attained in the reclaimed areas.

Potential Rate of Leachate Transport in Coal Seam No. 8

To evaluate the potential water-quality impact of mining/waste disposal operations to the main coal seam, a conceptual model for leachate transport was used. The conceptual model considered flow and discharge rates in the coal seam and hydrologic relationships of the coal seam to receptor points as a means of assessing leachate transport. The model entails the simplification of the coal seam flow system for calculation purposes. The model was designed such that simplification measures can be expected to bias the calculated outcome to over-predict leachate transport. Estimates of hydraulic variables and physical relationships used for the model are based on presently available data. Where variability exists in a given input value, the value selected for computations represents the highest or lowest reasonable value providing an over-prediction (or conservative estimate) of potential leachate migration.

As a measure of the potential rate of leachate transport in the coal seam, the velocity of ground water flow in the seam is considered. The velocity of flow in ground water can be determined using the following equation:

$$\overline{v} = K \cdot \frac{\Delta h}{\Delta l} \cdot \frac{1}{N_e}$$

where,

$\overline{v}$ = velocity of ground water along a given flow path, (ft/day),

K = hydraulic conductivity (permeability) (ft/day),

Δh = change in head along the given flow path (ft),

Δl = distance along a given flow path (ft), and

N_e = effective porosity.

The transmissivity and hydraulic conductivity (permeability) of the coal seam were determined as the result of air lift/recovery testing of Fruitland Coal Seam Wells Nos. 3, 8, 9 and 15. Hydraulic conductivity estimates and averages obtained from the testing are listed in Table 27.2.1-7.

Slug-type drawdown tests of the main coal seam were conducted by the USGS in support of an underground coal gasification study, 2 to 3 miles east of the mine (Neimczyk, 1980). From these tests, the hydraulic conductivity of the coal seam was determined to be about 10 millidarcy's or 0.0274 ft/day.

Based on tests conducted by SJCC and the USGS, the permeability of the coal seam appears to be very low and somewhat variable in the area of the mine. The permeability of the seam is primarily attributable to cleating and small scale fracturing of the coal. To provide a conservative estimate of flow in the coal seam, favoring higher flow and leachate transport rates, the highest value of hydraulic conductivity determined by SJCC (0.026 ft/day) will be used for calculating flow velocity.

Based on the potentiometric map of the main coal seam, gradients in the unit vary from about 0.01 to 0.001 feet per foot. The higher gradients are found in the area between the Yucca-Juniper and Cholla-Pinon Pits where the

TABLE 27.2.1-7. AIR LIFT/RECOVERY TEST ESTIMATES OF THE HYDRAULIC CONDUCTIVITY OF COAL SEAM NO. 8[1]

Well No. / Interpretive Method	3	9	15	Geometric Mean
Approximation	0.0260 ft/day	0.0008 ft/day	0.0092 ft/day	0.0058 ft/day
Numerical	0.0090 ft/day	0.0008 ft/day	0.004 ft/day	0.0031 ft/day
Arithmetic Mean	0.0175 ft/day	0.0008 ft/day	0.0066 ft/day	

1 For an explanation of the procedures and interpretative methods used by SJCC for air lift/ recovery testing of Coal Seam No. 8, refer to Chapter 12.

coal seam thins significantly. The lowest gradients are found in the northern and southern sections of the mine. Flow conditions in the northern section of the mine are probably respresentative of background conditions because of the distance from this area to the active mine pits and the thinning of the seam between the northern area and the pits.

In order to provide a high-end estimate of flow rates and thus leachate transport in the coal seam, a gradient of 0.01 feet per foot will be used. Higher gradients may occur in the coal seam in close proximity to the mine pits, but because of the localized nature of these gradients, they are not considered in the flow analysis for the coal seam as a unit.

Using the conservative values of hydraulic conductivity and hydraulic gradients for the coal seam as discussed above, and a value of effective porosity of 0.05 (based on the value of 0.05 for specific yield used for the pit inflow modeling) we have:

$$\bar{v} = [0.026 \text{ ft/day}] \cdot [0.01 \text{ ft}] \cdot [\frac{1}{0.05}]$$

or,

$$\bar{v} = 0.0052 \text{ ft/day} = 1.9 \text{ ft/year}$$

It is apparent that ground-water flow rates in the coal seam are very low. Because conservative values were used for determining the velocity of flow in the coal seam, 1.9 ft/year is probably higher than velocities which actually occur in this unit.

The transport of potential ground-water contaminants in the coal seam can be evaluated using the above value for flow. Possible receptor points for migrating contaminants include non-SJCC owned wells in the Fruitland Formation (presumably completed in Coal Seam No. 8), the San Juan River Valley alluvium and ultimately the San Juan River. The southern section of the mine is located approximately 3000 feet from the estimated location of the coal seam - alluvium contact at its closest point, as shown in Figure 27.2.1-9. Based on the estimate of velocity in the coal seam, and assuming that the leachate would take the shortest path of travel, it is estimated that about 1580 years would be required for leachate emanating from the southern mine area to reach the coal seam alluvium contact. Alternately, the northern area of the mine (the Cholla-Pinon Pit) lies approximately 18,000 feet from the coal seam-alluvium contact as shown in Figure 27.2.1.9. Travel time of the leachate along the path of shortest possible travel between the Cholla-Pinon Pit and the contact would be about 9470 years.

Additional receptor points of waste/spoil leachate in the coal seam are wells located in the area of the mine. An inventory of non-SJCC wells completed in the Quaternary alluvium, Pictured Cliffs Sandstone, Fruitland Formation and Kirtland Shale Formation in the area of the mine was compiled from literature sources. Locations and specifications for these wells have been included as Figure 27.2.1-10 and Table 27.2.1-8. respectively.

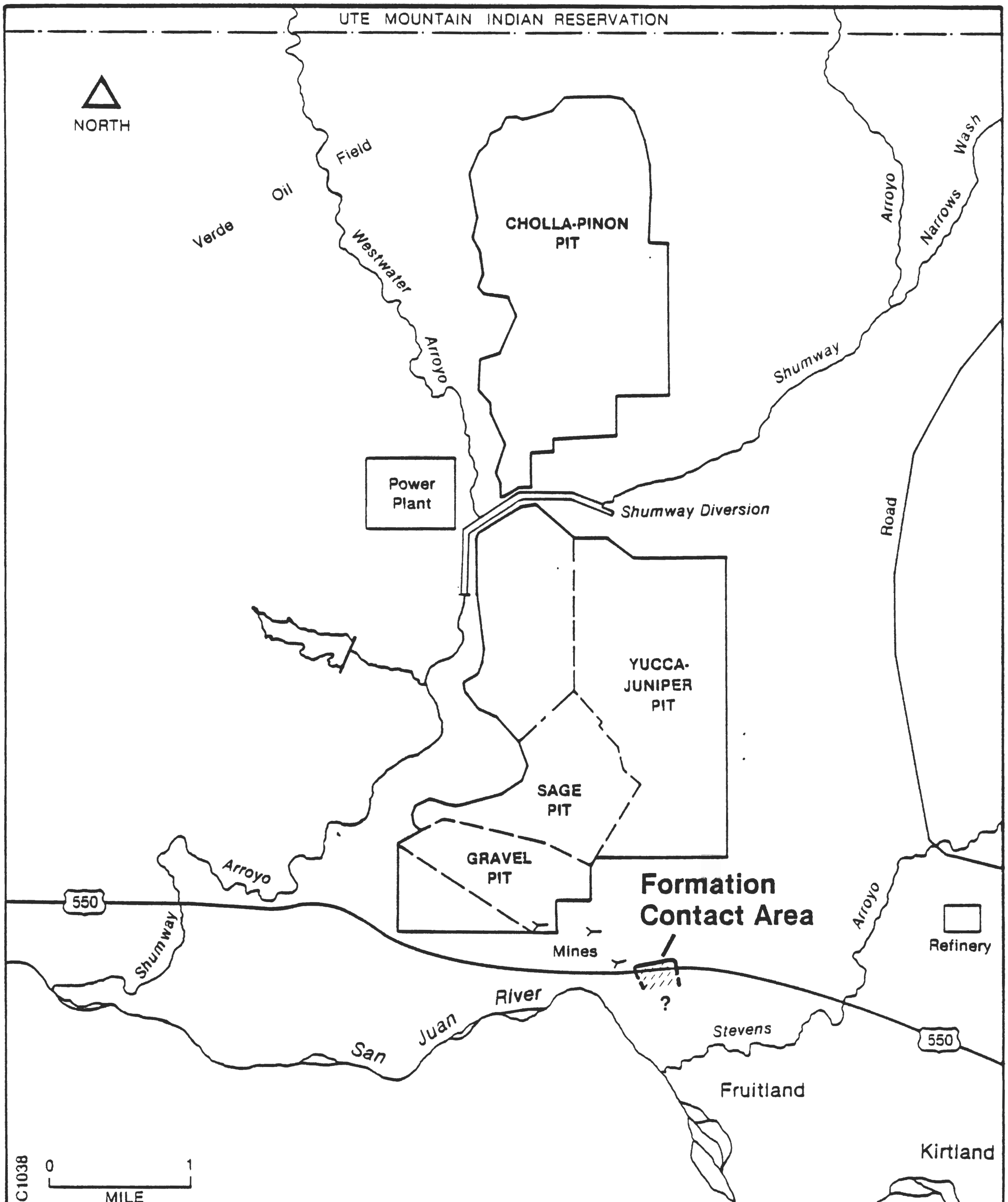


Figure 27.2.1-9. Estimated Location of Coal Seam - Alluvium Contact.

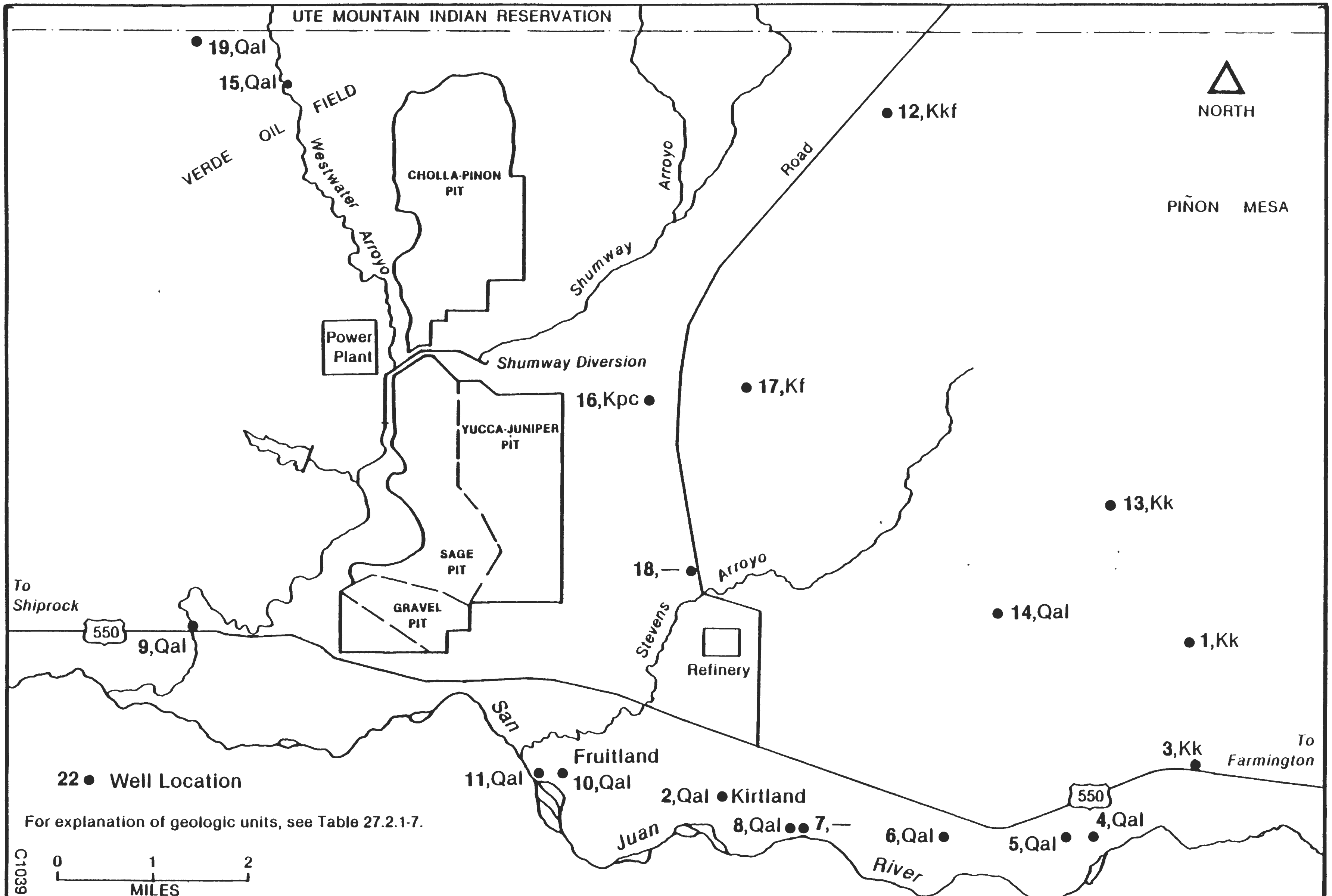


Figure 27.2.1-10. Locations of Non-SJCC Wells Completed in the Quaternary Alluvium, Pictured Cliffs Sandstone, Fruitland Formation and Kirtland Shale in the Area of the Mine.
(FROM: Stone, 1983 and Link, 1980.)

TABLE 27.2.1-8. SPECIFICATIONS OF NON-SJCC WELLS SHOWN IN FIGURE 27.2.1-10[1]

Well Number	Name	Depth (feet)	Alti-tude (feet)	Depth to Water (feet)	Date	Producing Interval (feet)	Principal Water-bearing Unit(s)[2]	Specific Conduct-ance (μmhos at 25°C)	Date	Remarks
1	Locke Arroyo	56	5,460	46.4	11/19/74	-	Kk	-	-	Abandoned.
2	Elmer Davidson	25	5,186	5	02/07/66	-	Qal	1,100	02/07/66	Drive point, location questionable.
3	Wesley B. Jones	500	5,445	154.9	11/19/74	-	Kk	-	-	Not used.
4	Steve Arnold	60	5,212	14.3	11/07/74	-	Qal	650	11/07/74	-
5	Alfred Stallings	38	5,200	23	11/19/74	-	Qal	870	11/19/74	-
6	Scott Broten	27	5,178	1.6	11/07/74	-	Qal	1,115	11/07/74	-
7	R.E. Dwyer	-	-	-	-	-	-	-	-	-
8	Gelman Trailer Park	-	-	-	-	-	Qal	-	-	-
9	R.V. Nichols	33	5,060	13.4	11/21/74	-	Qal	-	-	Driven well.
10	Wesleyan Navajo Mission	19	5,100	9	02/21/59		Qal	1,210	02/21/59	-
11	Fruitland Trading Co.	30	5,115	5	02/--/66	-	Qal	825	02/07/66	Driven well.
12	Wallace Ranch	-	5,460	56.9	11/21/74	-	Kkf	-	-	-
12	Harper	-	5,520	55.7	11/19/74	-	Kk	-	-	Windmill; not used.
14	Cline	11	5,365	8.1	11/19/74	-	Qal	-	-	-
15	Spring	-	5,322	-	-	-	Qal	6,000	11/05/75	Arroyo full of seeps from here to "Westwater Spring"; 30' excavated pool.
16	CDPC	730	5,260	124	05/23/78	613-730	Kpc	19,000	05/23/78	-
17	CDOB	582	5,330	121	05/23/78	546-582	Kf	16,000	05/23/78	-
18	CT2 Coal Well	500	5,280	133	05/23/78	470-500	-	6,570	05/23/78	-
19	Red Point Well	8	5,398	2.4	11/05/75	-	Qal	2,800	11/05/75	Development of Westwater Spring.

[1] From: Stone, 1983 and Link, 1980.

[2] Principal water bearing units:
- Quaternary
  - Qal - alluvium
- Cretaceous:
  - Kk - Kirtland Shale
  - Kkf - Kirtland Shale Fruitland Formation, undivided
  - Kf - Fruitland Formation
  - Kpc - Pictured Cliffs Sandstone

Based on the well inventory for the mine area, the closest non-SJCC well to the mine that is completed in the Fruitland Formation lies approximately 10,500 feet from the eastern border of the mine. Provided the direction of ground-water flow is to the east (which it apparently is not), the time of leachate travel to the well is estimated to be 5230 years. Wells completed in the alluvium to the south of the mine could possibly receive leachate-affected ground water following its arrival at the coal seam-alluvium contact.

The use of velocity to estimate time of contaminant travel to a given point ignores several mass-transport processes which serve to modify mass-transport by advection (flow of ground water). These processes include molecular diffusion, sorption and mechanical dispersion. Molecular diffusion in ground water is the spreading of dissolved species in response to concentration gradients as described by Fick's Second Law (Freeze, 1979). This process can cause dissolved species to move ahead of flow, but because diffusion processes are extremely slow they are normally ignored. Sorption/desorption and mechanical dispersion processes in ground water systems can cause contaminants to lag behind flow as discussed in 27.2.1.2. In the case of the coal seam, travel times estimated by simply considering flow (advection) will provide a reasonable and perhaps conservative estimate of time of first arrival.

Estimated Quantity of Leachate-Affected Ground Water to be Potentially Received by the San Juan River and Alluvial Aquifer

In order to evaluate the potential impact of leachate on the San Juan River and associated alluvial aquifer, the volume of flow received from the mine area by the river valley alluvium, and ultimately, the river is evaluated. As discussed earlier, the contact area of the San Juan alluvial aquifer and the main coal seam serves as a discharge point for the coal seam. Little is known about how much of the coal seam water which flows through the mine area is discharged at the outcrop of the seam along the walls of the San Juan River Valley, and at the coal seam contact. Some water flowing through the mine area may not be discharged to the river valley but may continue to flow downdip.

In the interest of arriving at a conservative estimate of leachate production to the alluvial aquifer and river, it is assumed that all coal-seam ground water which flows through the mine area will produce leachate and that this leachate will enter the alluvial aquifer at the coal seam-alluvium contact. Given that the general direction of flow through the mine is to the southeast and that the lateral extent of the mine normal to this flow direction is approximately 18,500 feet (as shown in Figure 27.2.1-11), the discharge of leachate to the alluvium can be estimated using the following equation:

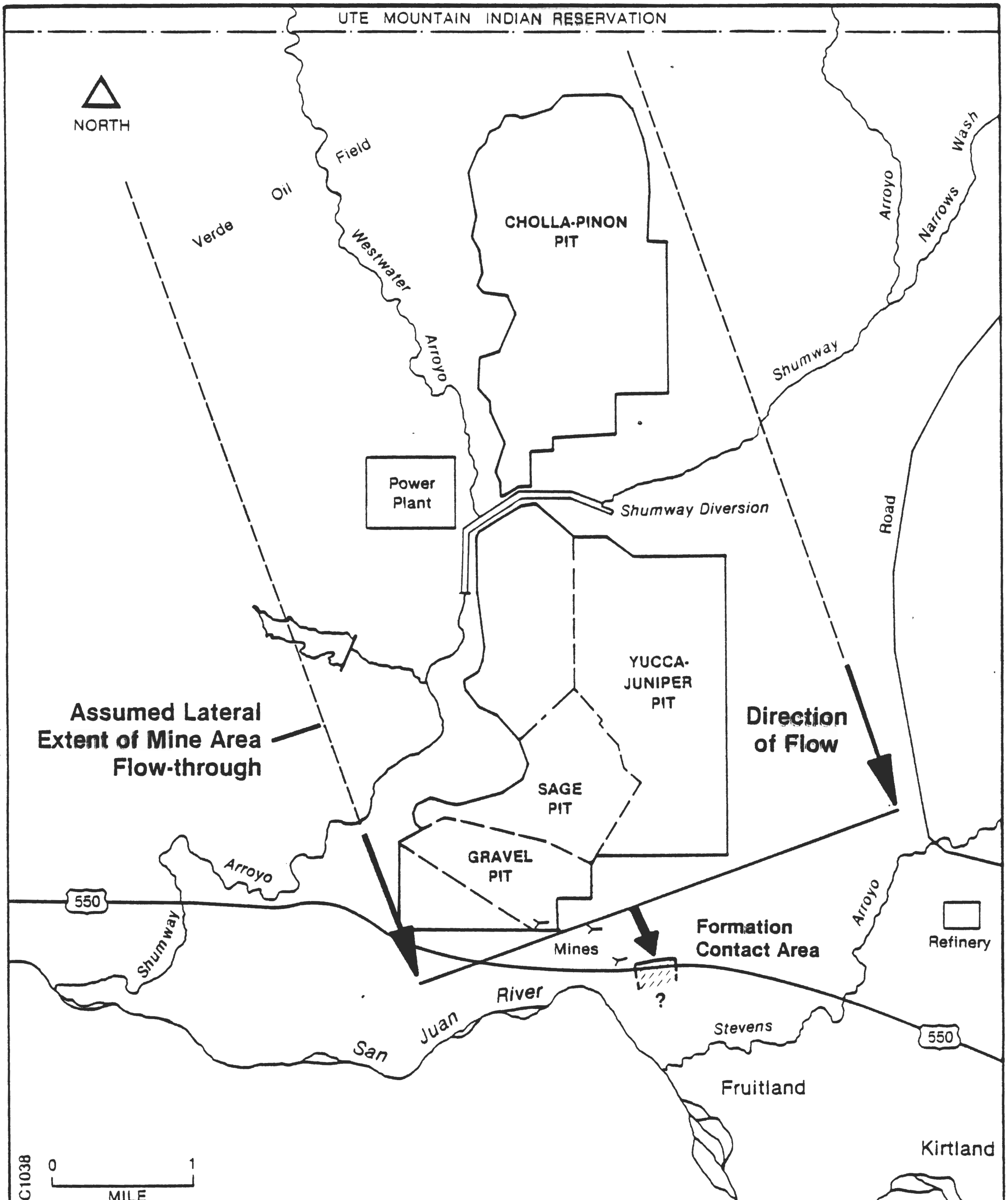


Figure 27.2.1-11. Average Direction of Flow and Lateral Extent of Flow for the Determination of Potential Discharge to the Alluvial Aquifer.

$$Q = \overline{v} \cdot N_e \cdot L \cdot M$$

where,

Q = estimated discharge of leachate affected ground water from the mine to the alluvial aquifer (ft^3/yr)

$\overline{v}$ = velocity of ground water in the main coal seam = 1.9 ft/yr

N_e = effective porosity of the coal seam = 0.05

L = lateral extent of the mine normal to the general direction of flow in the coal seam = 18,500 ft

M = estimated average thickness of the coal seam in the southern area of the mine = 16 ft

substituting, we have:

$$Q = [1.9 \text{ ft/yr}] \cdot [0.05] \cdot [18{,}500 \text{ ft}] \cdot [16 \text{ ft}]$$

or:

$$Q = 28{,}120 \text{ ft}^3/\text{yr}$$

Based upon the gross overestimations used for the estimation of the yearly production of leachate-affected ground water to the alluvial aquifer, it is felt that the actual value will be considerably less. The results of these calculations demonstrate that the annual production of leachate-affected ground water to the River Valley is small, especially when compared to average flow in the San Juan River.

It is reported that the contributions to the San Juan River Valley alluvium from bedrock sources is small (Stone, 1983). Historical low discharges of 14 and 8 cubic feet per second reported for the San Juan River at the Farmington and Shiprock, New Mexico gaging stations, respectively (Ref. 1, 1983), support this contention. In addition, relatively low values of specific conductivity for wells completed in the alluvial

Based on the above calculations it is evident that leachate-affected ground water will potentially contribute only a minor fraction of flow to the San Juan River, even under extreme low-flow conditions. Thus, if the leachate-affected ground water is not significantly contaminated there will be little if any effect to the quality of the San Juan River as the result of leachate contributions from the coal seam.

Wells completed in the river valley alluvial aquifer, in the vicinity of the coal seam alluvium contact, may potentially be impacted by leachate affected ground water. Although there are apparently no wells in the near-vicinity of the contact area, high values of permeability (Stone, 1983) may allow leachate affected ground water to move rapidly toward wells. Put into perspective, the estimated annual production of leachate 28,120 ft^3, is roughly equivalent to the annual production of a well operating at 0.40 gallons per minute on a continuous basis.

Therefore, if the alluvial aquifer is subjected to significant quantities of discharge by pumping or withdrawal by riparian vegetation, the contribution of leachate from the coal seam with respect to water received from the river will be small. Should water quality in the alluvium near the outcrop area be significantly affected by a poor quality leachate, wells in the vicinity of the outcrop could be moved closer to the river. This would allow the San Juan River to provide a relatively larger contribution to well production because of the river's potential as a recharge boundary.

aquifer in the area of the mine, suggest that poor quality water from bedrock sources is not a major source of recharge to the aquifer.

Mean discharge for the San Juan River at the Farmington and Shiprock gaging stations is reported at 2,370 and 2,175 cubic feet per second, respectively (Stone, 1983). In relation to the conservative estimate of leachate production to the alluvial aquifer and San Juan River from the coal seam, streamflows are very large. Using the mean flow of the San Juan River at the Shiprock station (as a conservative estimate for the San Juan River near Waterflow, New Mexico) the ratio of the estimated discharge of leachate-affected ground water from the coal seam to average discharge in the San Juan River is:

$$R = \frac{Q_c}{Q_r}$$

where:

Q_c = estimated discharge of leachate affected ground water from the main coal seam to the San Juan River = 28,120 ft^3/yr.

Q_r = mean annual flow in the San Juan River at the Shiprock Station = 2,175 $ft^3/sec \times 3.1536 \times 10^7 \frac{sec}{yr} = 6.859 \times 10^{10}\ ft^3/yr$.

or:

$$R = \frac{28{,}120\ ft/yr.}{6.859 \times 10^{10}\ ft^3/yr.} = 4.099 \times 10^{-7}$$

If the historical low discharge of 8 ft /sec or $2.523 \times 10^8\ ft^3/yr.$ at the Shiprock Gaging Station is used, the ratio becomes:

$$R = \frac{28{,}120\ ft^3/yr.}{2.523 \times 10^8\ ft^3/yr.} = 1.056 \times 10^{-4}$$

27.2.1.4 Summary

Results from the laboratory study indicate that a representative composite of the waste materials (fly ash, bottom ash and neutralizer sludge in their respective production ratios) contains mainly aluminum and calcium. The composited waste was determined to be well below the RCRA EP toxicity criteria.

From the leaching studies it was determined that the spoil-plus-waste mixture leachate exceeded the concentrations in the spoil leachate and ground water for some chemical parameters. However, the spoil leachate was higher in a few trace elements and the ground water was highest in cyanide and some salts. All three waters exceeded the New Mexico Quality Control Commission (NMQCC) Standards for ground water for fluoride, chloride, and pH. Leachate from the spoil also exceeded the arsenic and boron criteria.

The attenuation studies for the leachates in the coal seam showed that many species in the waste and spoil leachate were reduced after interaction with the coal. However, some species were contributed by the coal. The attenuated leachates exceeded the NMQCC standards for boron, chloride, fluoride, and pH. The ground water also exceeded the fluoride, chloride and pH criteria, thus concentrations of boron in the attenuated leachate are noteworthy.

Calculated relative migration rates of attenuated species from the spoil-plus-waste leachate indicate that the contamination front can be assumed to travel through the coal seam at a highly retarded rate compared to the velocity of water flow through the seam. For instance, concentrations of TDS, sulfate and boron can be expected to be retarded by a factor of 10^{-1} based on these determinations. Several species exihibited an even higher potential for retardation such as aluminum, which exhibited the highest retardation tendency (relative retardation factor of 10^{-5}).

Of the three water bearing units in the mine area, coal seam No. 8 of the Fruitland Formation was considered to be the unit of principal concern with respect to potential leachate transport. For the evaluation of potential leachate transport, a conservative estimate of flow velocity in the coal seam was determined to be 1.9 ft/yr. Based on this flow rate, the time of travel of leachate affected ground water to receptor points is large with travel time maximized from points of origin in the northern area of the lease.

The shortest time of travel for leachate affected ground water to a potential receptor point was estimated to be about 1600 years (leachate affected ground water traveling to the San Juan River Valley from the extreme southern boundary of the mine area). Retardation factors developed in the laboratory studies indicate that many species/parameters of interest will lag significantly behind the flow of ground water in the coal seam. For instance, when the retardation factor of 10^{-1} for TDS is considered, it is evident that the effects of leachate induced TDS impacts on ground-water will propagate very slowly and will be felt by potential receptor points only after significant periods of time.

Wells completed in the Fruitland Formation and the San Juan River Valley alluvium may potentially be impacted by mining operations. However, as discussed earlier, the estimated time of travel of leachate affected ground water to the wells will probably be very large.

Wells completed in the Quaternary Alluvium of the San Juan River Valley may intercept leachate affected ground water received from the coal-seam-alluvium contact. There exists a significant potential for the dilution of the leachate affected ground water by recharge to the alluvium received from the San Juan River. Leachate affected ground water which potentially comes into contact with the waters of the San Juan River will undergo very high dilution (assuming total mixing). This high dilution potential exists, even when historical low flows in the San Juan River are considered.

Within the framework of this study, the significance of potential ground-water quality impacts appears to be minimal based on: 1) the estimated quality of leachate from the mine spoil and power plant wastes in comparison to poor ground water quality in units directly contacted by the mine: 2) the apparent chemical attenuation (retardation) potential of the No. 8 coal seam; 3) the low velocity of flow in the coal seam; and 4) the high potential for dilution of leachate affected ground water received by the major receptor points (San Juan River and San Juan River Valley Alluvial Aquifer).

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Input Into 27.7.0

At present there are 15 monitor wells located in the mine area which are considered suitable for the collection of ground-water information from Coal Seam No. 8. These wells are illustrated in Exhibit 12. The wells located in the northern area (Cholla-Pinon Pit) of the mine are at present upgradient from mining operations and thus provide background water-quality data. As mining proceeds, these wells may have to be abandoned. Where wells are to be abandoned, they should have "twinned" replacements. In other words, each well should be replaced with two wells, one upgradient and one downgradient of the mine area.

After reclamation activities have commenced in the northern mine area, it may be advantageous to place additional or replacement monitor wells immediately along the southern and western boundaries of the Cholla-Pinon Pit so that leachate-affected ground water in the coal seam can be detected and evaluated as early as possible. Upgradient wells for the northern area should be located northwest of the Cholla-Pinon Pit.

Wells completed in the main coal seam in the southern section of the mine lie primarily to the east of the present mining operations. It is felt that additional monitor wells are needed in the southern mine area to the south and southwest of the Sage and Gravel Pits. These wells are needed to intercept possible leachate affected water traveling toward the San Juan River. As existing wells in the southern mine area are abandoned because of mining operations, they should have "twinned" replacements. Down-gradient replacement wells should be positioned along the southern and eastern limits of the southern mine area. Upgradient wells should be located just to the north and to the west of the southern mine area.

Additional wells, completed within the reclaimed mine areas, may be useful for tracking water quality and water level effects within the backfilled areas. Data derived from these wells can be used to evaluate/verify the results and conclusions of the water quality impact assessment performed for this study. In the case of all monitor wells, all wells should be constructed so as to provide a representative sample from the unit screened. Drilling and completion methods should prescribe to accepted standards for water quality monitor wells.

For each of the monitor wells (including wells completed in the alluvium and Pictured Cliffs Sandstone), water level measurements should be taken on a monthly basis to evaluate the one-time water-level data used in this study. Following the first year, water levels in the various units should be measured quarterly so that seasonal and man-made fluctuations can be tracked.

Ground-water quality samples should be collected at regular intervals from the main coal seam, alluvium, and Pictured Cliffs Sandstone wells throughout and following the life of the mine. Samples should be collected for analysis from the alluvium on a quarterly basis because of the potential seasonality of water quality in this unit. The potentially deeper and less active water bearing formations, namely the coal seam and the Pictured Cliffs Sandstone ground water should be sampled on a yearly basis.

Ground-water sampling would be optimized with the use of a stainless-steel and Teflon® bladder or gear-type pump. The use of such a pump would help to ensure that hygiene of collected samples would be maintained. All samples should be sotred and preserved by the methods described in 27.2.1.2. For the sake of consistency, all ground-water samples should be analyzed for the constituents listed in Table 27.2.1-5. However, after several sample sets have been compiled, the list of parameters to be analyzed may be justifiably shortened based on the significance of the analytical findings.